Contents

BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

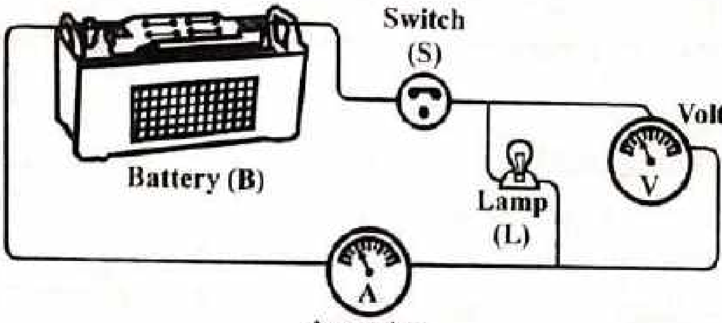
UNIT 1

D.C. CIRCUITS

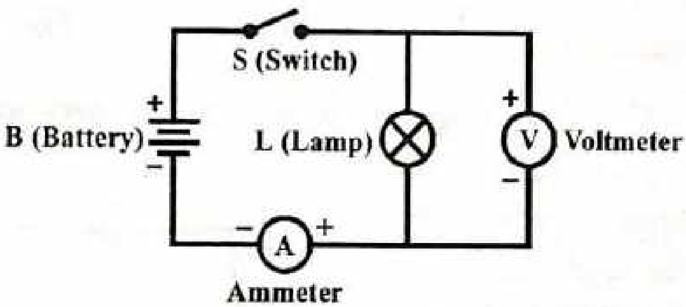
VOLTAGE AND CURRENT SOURCES, DEPENDENT AND INDEPENDENT SOURCES, UNITS AND DIMENSIONS, SOURCE CONVERSION

Q.1. What do you mean by D.C. circuit ?

Ans. A closed path followed by direct current (D.C.) is known as D.C. circuit. It contains a D.C. source, a load, a switch, connecting leads and measuring instruments such as ammeter and voltmeter. Fig. 1.1 (a) shows a simple D.C. circuit and fig. 1.1 (b) shows the simplified line diagram of the same D.C. circuit. The load resistors can be connected in series, parallel or series-parallel combination as per the requirement.



(a) Simple D.C. Circuit



(b) Line Diagram of D.C. Circuit

Fig. 1.1

Q.2. Distinguish the voltage source and current source.

(R.G.P.V., June 2013)

Or

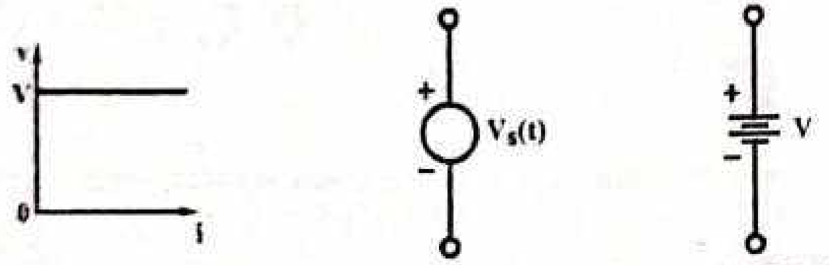
Define voltage and current sources. ***(R.G.P.V., June 2014)***

Ans. **Ideal Voltage Source** – A independent voltage source is a two terminal device whose voltage at any instant of time is independent of the current flowing through its terminals. It controls the magnitude and waveform

of its terminal voltage. The equation of voltage source in v-i plane [fig. 1.2 (a)] is given by

$$v = \text{Constant}$$

The equation, $v = V_m \sin\omega t$, represents a voltage source, where the voltage v is varying with time. However the voltage is independent of the current i and, therefore is a constant as far as the v-i plane is concerned.



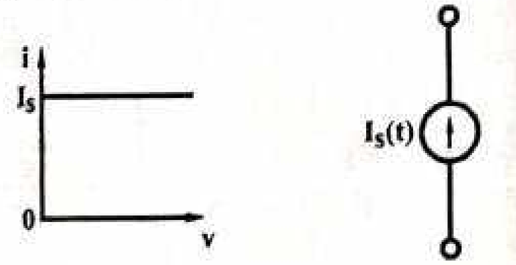
(a) Characteristics *(b) Symbol* *(c) Symbol*

Fig. 1.2 Ideal Voltage Source

Ideal Current Source – A current source is a two terminal device whose current at any instant of time is independent of voltage across its terminals. It controls the magnitude and waveform of its current. Mathematically, the equation of a current source in i-v plane [fig. 1.3 (a)] is given by

$$i = \text{Constant}$$

The equation $i = I_m \sin\omega t$, is the equation of an ideal current source, because the curent i is independent of the voltage in i-v plane. Characteristics and symbol of an ideal current source are shown in figs. 1.3 (a) and (b) respectively.

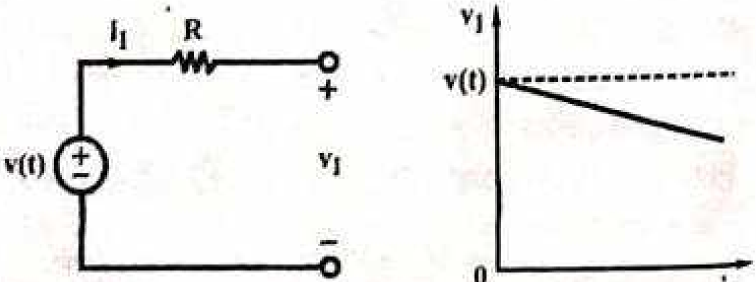


(a) Characteristics *(b) Symbol*

Fig. 1.3 Ideal Current Source

Q.3. Define the practical voltage source with its characteristics.

Ans. In this source, the voltage across the terminals of the source keep falling as the current through it increases. This behaviour is obtained by putting a resistance in series with an ideal voltage source as shown in fig. 1.4 (a). Then the terminal voltage v_1 is



(a) Model *(b) Characteristics*

Fig. 1.4 Practical Voltage Source

$$v_1 = v - i_1 R$$

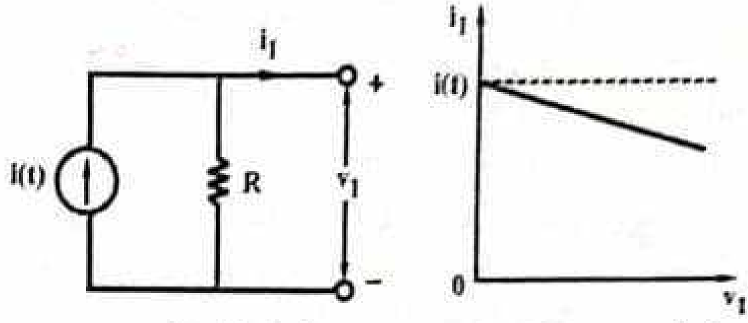
The practical voltage source approaches the ideal voltage source in the limit R becoming zero.

Q.4. Define practical current source with its characteristics.

Ans. In this source, the current through the source decreases as the voltage across it increases. This behaviour can be obtained by putting a resistance across the terminals of the source as shown in fig. 1.5 (a). Then the terminal current is

$$i_1 = i - \frac{v_1}{R}$$

The practical current source approaches the ideal current source in the limit R becoming infinity.



(a) Model *(b) Characteristics*

Fig. 1.5 Practical Current Source

Q.5. What do you understand by dependent and independent sources ? Explain with neat sketches. ***(R.G.P.V., Dec. 2011)***

Or

Distinguish between dependent sources and independent sources. ***(R.G.P.V., June 2014)***

Ans. **Dependent Source –** In a dependent source, the output voltage or current depends on another voltage or current. The relationship may be linear or non-linear. The dependent source is fundamentally a three terminal device. The three terminal are paired, with one common terminal and one pair is known as input while the other pair as the output.

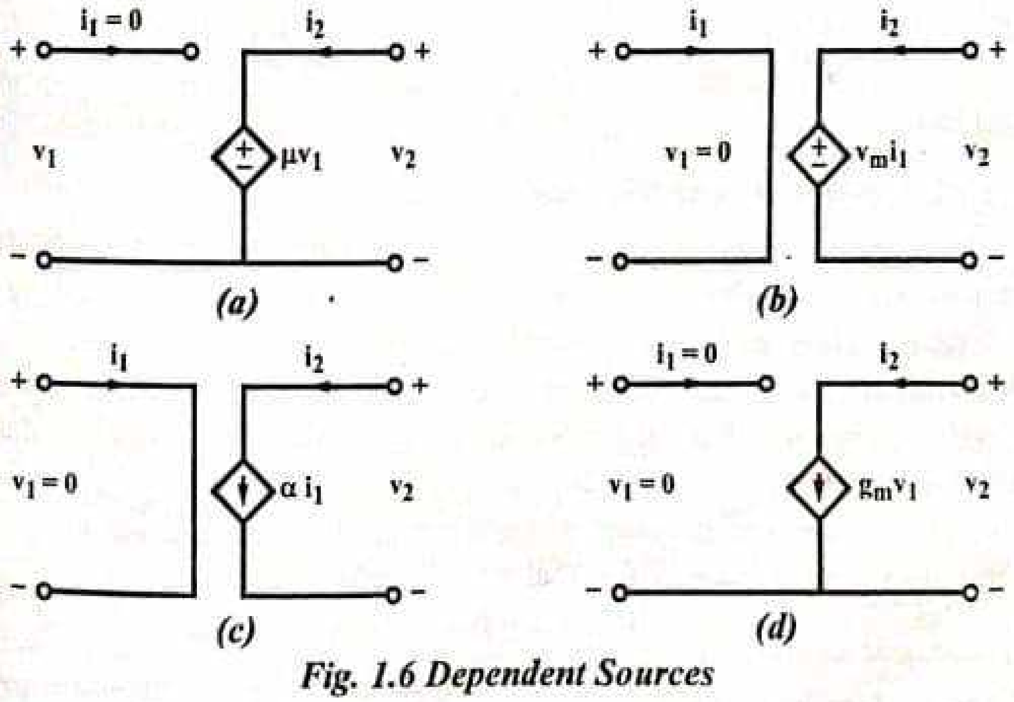


Fig. 1.6 Dependent Sources

Dependent sources are of four types as follows –

(i) Voltage dependent voltage source is shown in fig. 1.6 (a).

(ii) Current dependent voltage source is shown in fig. 1.6 (b).

(iii) Current dependent current source is shown in fig. 1.6 (c).

(iv) Voltage dependent current source is shown in fig. 1.6 (d).

Independent Source – The independent source is not dependent on any other quantity in the circuit it has a constant value i.e., the strength of voltage or current is not changed by any variation in the connected network. The independent sources are of two types i.e., independent voltage source and independent current source.

Q.6. Write the major difference between –

(i) Ideal voltage source and practical voltage source

(ii) Dependent and independent sources.

(R.G.P.V., Dec. 2014)

Ans. (i) Ideal Voltage Source and Practical Voltage Source – Refer the ans. of Q.2 and Q.3.

(ii) Dependent and Independent Sources – Refer the ans. of Q.5.

Q.7. Write down the various types of units.

Ans. The various types of unit are given below –

(i) The French System or C.G.S. System – In this system, the units of length, mass and time are centimetre, gramme and second respectively.

(ii) The British or F.P.S. System – In this system, the units of length, mass and time are foot, pound and second respectively.

(iii) Metre-Kilogram-Second or M.K.S. Sytem – In this system, the units of length, mass and time are metre, kilogram and second respectively.

(iv) International System of Units or S.I. System – In French, SI stands for *systeme internationale d'unites*. It is the modern form of metric system.

Q.8. Explain in brief S.I. units.

Ans. The S.I. system is a comprehensive, logical and coherent system, designed for use in all branches of science, engineering and technology.

The S.I. units are accepted as the legal system of units for measurement in most countries in the world. For example, the unit for length is metre and the unit for area which is the product of a length by another length is (metre × metre) or metre^2.

The international standard of units is based on seven units with a unit symbol assigned to each of them as given in table 1.1.

Table 1.1 Base Units

S.No.	*Physical Quantity*	*S.I. Unit*	*Symbol*	*Dimensional Notation*
(i)	Length	Metre	m	[L]
(ii)	Mass	Kilogram	kg	[M]

(iii)	Time	Second	s	[T]
(iv)	Electric current	Ampere	A	[I]
(v)	Temperature	Kelvin	K	[θ]
(vi)	Luminous intensity	Candela	Cd	[ϕ]
(vii)	Amount of substance	Mole	mol	[mol]

The plane angle and solid angle are known as supplementary units. Table 1.2 shows two dimensionless supplementary units.

Table 1.2 Supplementary Units

(i)	Plane angle	Radian	rad
(ii)	Solid angle	Steradian	sr

Q.9. Discuss the concept of dimension.

Ans. The length, mass and time are considered as the three base dimensions. These are indicated by letters [L], [M] and [T] respectively. Dimension of physical quantity simply represents the physical quantities that appear in that quantity and gives absolutely no idea about the magnitude of the quantity. The quantity is said to be zero dimension when a quantity does not depend upon any of the base units. A quantity which is indicated as the product of two same dimensions will have two dimensions of that unit.

For example, the dimension of area will be –

$$[\text{Area}] = [\text{Length}].[\text{Length}] = [\text{Length}^2] = [L^2]$$

A quantity which does not depend upon any one base units is called zero dimension of the units upon which the quantity does not depend.

For example, volume does not depend upon mass and time, therefore the mass and time dimension of volume will be zero.

The following dimensional relationships for electrical or mechanical quantities are obtained –

$$
\begin{array}{llll}
[\text{Area}] & = [\text{Length}]^2 & = [L]^2 & = [L^2] \\
[\text{Volume}] & = [\text{Length}]^3 & = [L]^3 & = [L^3] \\
[\text{Density}] & = [\text{Mass}] / [\text{Volume}] & = [M]\,[L]^{-3} & = [ML^{-3}] \\
[\text{Velocity}] & = [\text{Length}] / [\text{Time}] & = [L]\,[T]^{-1} & = [LT^{-1}] \\
[\text{Acceleration}] & = [\text{Length}] / [\text{Time}]^2 & = [L]\,[T]^{-2} & = [LT^{-2}] \\
[\text{Force}] & = [\text{Mass}]\,[\text{Acceleration}] & = [M]\,[L]\,[T]^{-2} & = [MLT^{-2}] \\
[\text{Work}] & = [\text{Force}]\,[\text{Distance}] & = [M]\,[L]^2\,[T]^{-2} & = [ML^2T^{-2}]
\end{array}
$$

Q.10. Write short note on derived units.

Ans. All other quantities which can be expressed in terms of other quantities are known as derived quantities and the units in which these quantities are measured are called derived units. Some of which have special names given in table 1.3.

Table 1.3 Some Special Derived Units

S.No.	Physical Quantity	S.I. Unit	Dimensions
(i)	Frequency	Hertz (Hz = cs^{-1})	$[T^{-1}]$
(ii)	Force	Newton (N = $kgms^{-2}$)	$[MLT^{-2}]$
(iii)	Power	Watt (W = J/s)	$[ML^2T^{-3}]$
(iv)	Electric charge	Coulomb (C = As)	[IT]
(v)	Work, energy, quantity of heat	Joule (J = Nm)	$\{ML^2T^{-2}]$
(vi)	Electric resistance	Ohm (Ω = V/A)	$[I^{-2}ML^2T^{-3}]$
(vii)	Electric potential	Volt (V = W/A)	$[I^{-1}ML^2T^{-3}]$
(viii)	Electric capacitance	Farad (F = As/V)	$[I^2M^{-1}L^{-2}T^4]$
(ix)	Electric conductance	Siemens or mho (S = A/V)	$[I^2M^{-1}L^{-2}T^3]$
(x)	Inductance	Henry (H = Vs/A)	$[I^{-2}ML^2T^{-2}]$
(xi)	Pressure	Pascal (P_a = N/m)	$[MT^{-2}]$
(xii)	Customary Temperature	Degree celsius (°C)	[θ]
(xiii)	Magnetic flux	Weber (Wb = Vs)	$[I^{-1}ML^2T^{-2}]$
(xiv)	Magnetic flux density	Tesla (T = Wb/m^2)	$[I^{-1}MT^{-2}]$

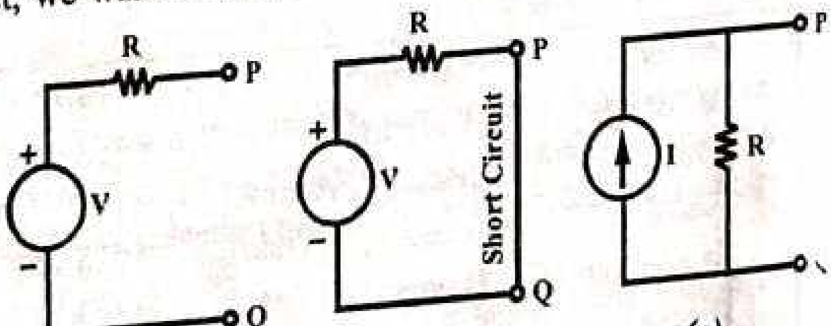
Q.11. Explain source transformation.

(R.G.P.V., Dec. 2006, Nov./Dec. 2007)

Or

Explain the source transformation technique. *[R.G.P.V., Nov. 2018 (O)]*

Ans. A given voltage source with a series resistance can be converted into an equivalent current source with a parallel resistance. Conversely a current source with a parallel resistance can be converted into a voltage source with a series resistance. Let, we want to convert the voltage source of fig. 1.7 (a) into an equivalent current source. Primarily we will find the value of current supplied by the source when a short circuit is put across its terminals P and Q as shown in fig. 1.7 (b). This current is I = V/R.



(a) (b) (c)

Fig. 1.7

A current source supplying this current I and having the same resistance R connected in parallel with it represents the equivalent source. It is shown in fig. 1.7 (c). Similarly a current source of I and a parallel resistance R can be

converted into a voltage source of voltage V = IR and a resistance R in series with it. It should be kept in mind that a voltage source-series resistance combination is equivalent to a current source-parallel resistance combination, if –

(i) Respective open-circuit voltages are equal

(ii) Respective short-circuit currents are equal.

Q.12. Explain ideal voltage source and ideal current source with neat diagrams. How ideal voltage source can be converted into ideal current source? ***(R.G.P.V., Dec. 2010)***

Ans. **Ideal Voltage and Current Sources** – Refer the ans. of Q.2.

For transformation of ideal voltage source to an ideal current source, the value of resistance in fig. 1.8 (a) should be zero to make it an ideal voltage source and the value of resistance in fig. 1.8 (b) should be infinite to make it an ideal current source.

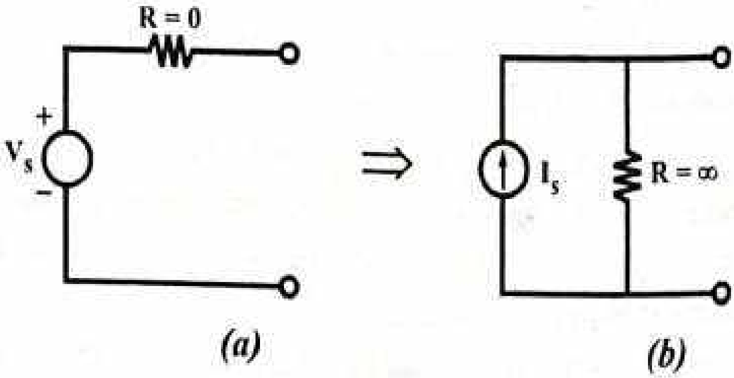


Fig. 1.8

OHM'S LAW, KIRCHHOFF'S LAW

Q.13. State and explain Ohm's law.

Ans. A definite relation exists among the three quantities namely applied voltage, current and resistance. This relation was expressed first of all by George Simon Ohm. This is called Ohm's law.

It states that the current flowing between any two points of a conductor (or circuit) is directly proportional to the potential difference across them, given physical conditions (i.e. temperature etc.) do not change. Mathematically, it is expressed as –

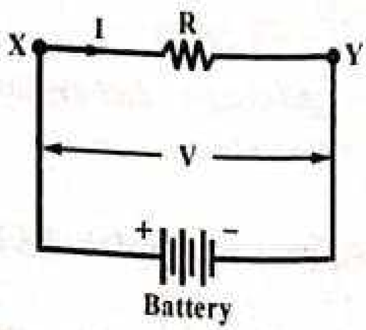


Fig. 1.9

$$I \propto V$$

or $$\frac{V}{I} = \text{Constant}$$

or $$\frac{V_1}{I_1} = \frac{V_2}{I_2} = \ldots\ldots = \frac{V_n}{I_n} = \text{Constant}$$

This constant is known as resistance (R) of the conductor. It is measured in Ohms.

$$\frac{V}{I} = R$$

or

$$V = IR \text{ or } I = \frac{V}{R}$$

Q.14. Differentiate between the following –

(i) Loop and mesh ***(R.G.P.V., June 2009, 2010)***

(ii) Node and junction. ***(R.G.P.V., June 2009, 2010)***

(iii) Active and passive element ***(R.G.P.V., June 2009, 2010)***

Ans. (i) Loop and Mesh – The closed path of a circuit is known as loop. The most elementary form of a loop which cannot be further divided is known as mesh.

(ii) Node and Junction – Node is a point in a circuit where two or more circuit elements are connected together. Junction is a point of a network where three or more circuit elements are joined. Infact, it is a point where current is divided.

(iii) Active and Passive Element – The elements which supply energy to the network are called active elements. The active elements may be constant voltage source or constant current source. The elements which receives energy from the network is called passive elment. The passive elements may be resistor, inductor or capacitor.

Q.15. What do you mean by bilateral network ?

Ans. A network whose properties remains same in either directions is called bilateral network. In other words, a circuit whose characteristic, behaviour is same irrespective of the direction of current through various elements of it, is called bilateral network. Network consisting only resistances is good example of bilateral network.

Q.16. State and explain Kirchhoff's current and voltage law.

(R.G.P.V., Feb. 2010, March/April 2010)

Or

State and explain KCL and KVL. ***(R.G.P.V., June 2017)***

Or

State and explain with neat diagram Kirchhoff's laws for electrical circuits. ***(R.G.P.V., Dec. 2017)***

Or

Explain Kirchhoff's current law and voltage law. ***(R.G.P.V., May 2018)***

Or

Write short note on Kirchhoff's law. ***(R.G.P.V., May 2019)***

Ans. ***(i) Kirchhoff's Current Law (KCL)*** – Kirchhoff's current law states that the algebraic sum of all branch currents leaving a node is zero at all instants of time. It is based on the principle of conservation of charge. The charge which enters a node must leave that node because it cannot be stored there. Since the algebraic sum of charge equals to zero, the time derivative of this summation must also be zero.

In fig. 1.10, the currents I_1, I_2, I_3, I_4, I_5 and I_6 is flow through the branches which are connected to a node ①. Currents I_1, I_3 and I_5 entering into the node while the currents I_2, I_4 and I_6 leaving the node. According to Kirchhoff's current law the sum of the currents flowing towards the node must be equal to the sum of the currents flowing out of the node,

$$I_1 + I_3 + I_5 = I_2 + I_4 + I_6$$

or
$$I_1 - I_2 + I_3 - I_4 + I_5 - I_6 = 0$$

or
$$\Sigma I = 0$$

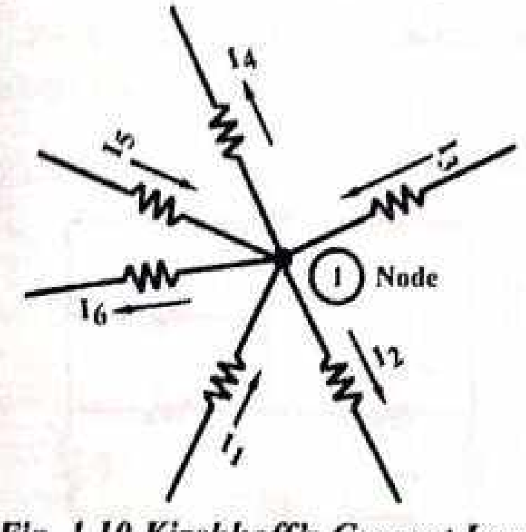


Fig. 1.10 Kirchhoff's Current Law

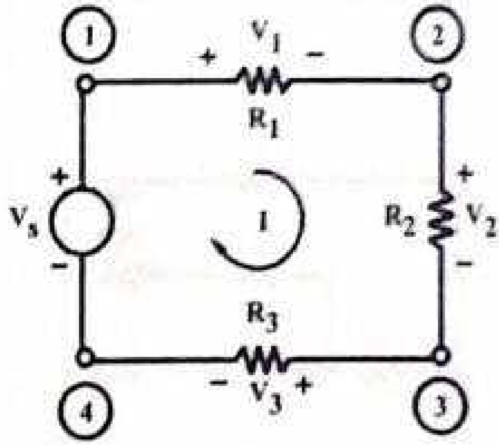


Fig. 1.11 Kirchhoff's Voltage Law

(ii) Kirchhoff's Voltage Law (KVL) – Kirchhoff's voltage law states that algebraic sum of all branch voltages around any closed loop of a network is zero at all instants of time. This law is based on the law of conservation of energy. KVL is valid for a circuit or at least for its mathematical model but it is not true for a general path in a region of space containing time varying magnetic fields.

Fig. 1.11 having nodes ①, ②, ③ and ④. Let the unit charge placed at node ① in the network. This charge is moved from node ① to ②, ② to ③, ③ to ④ and finally, it moves from ④ to ①. The decrease in energy in moving from ① to ② is identified as voltage drop whereas the increase in energy in going from ④ to ① is identified as voltage rise. If we assign a negative sign for a voltage rise and a positive sign for a voltage drop.

$$\therefore \quad V_1 + V_2 + V_3 - V_s = 0$$

$$V_1 + V_2 + V_3 = V_s \text{ or } \Sigma V = 0$$

NUMERICAL PROBLEMS

Prob.1. Find the value of current 'I'.

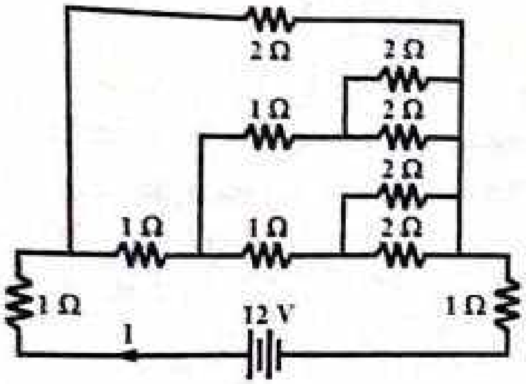


Fig. 1.12 *(R.G.P.V., June 2016)*

Sol. Resistances 2 Ω and 2 Ω are in parallel (fig. 1.12), i.e.

$$= \frac{2 \times 2}{2+2} = 1\,\Omega$$

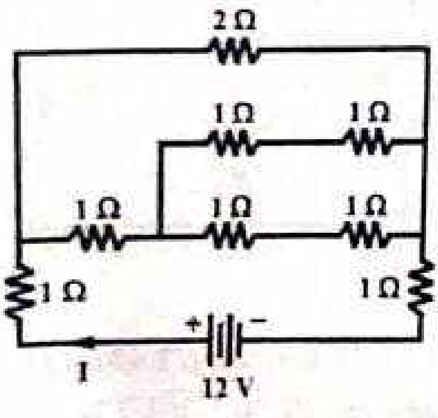


Fig. 1.13 (a)

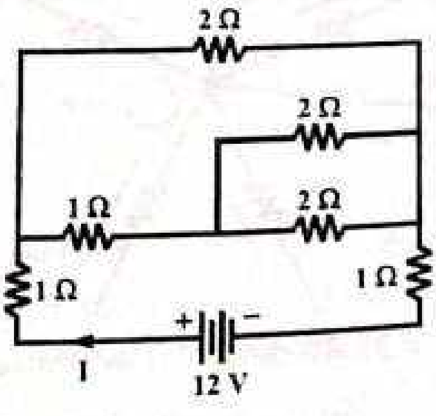


Fig. 1.13 (b)

Resistances 1 Ω and 1 Ω are in series [fig. 1.13 (a)], i.e. = 1 + 1 = 2 Ω

Resistances 2 Ω and 2 Ω are in parallel [fig. 1.13 (b)], i.e. $= \frac{2 \times 2}{2+2} = 1\,\Omega$

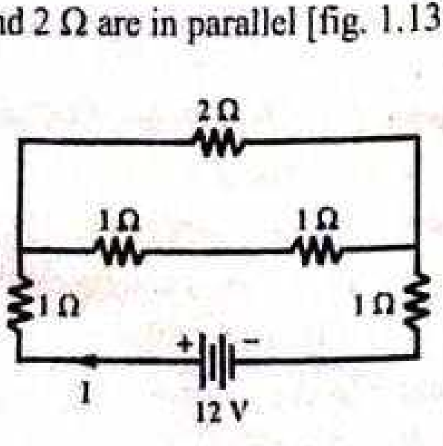


Fig. 1.13 (c)

Resistances 1 Ω and 1 Ω are in series and parallel with 2 Ω [fig. 1.13 (c)]. The simplified circuit is shown in fig. 1.13 (d) and fig. 1.13 (e).

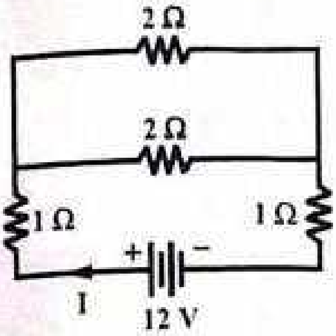


Fig. 1.13 (d)

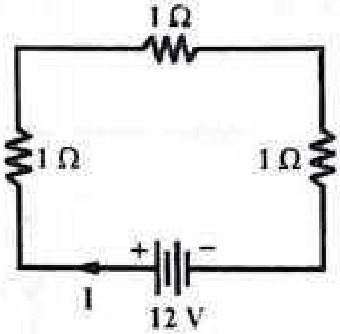


Fig. 1.13 (e)

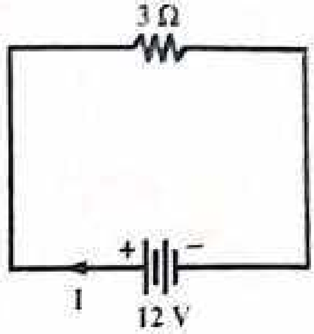


Fig. 1.13 (f)

The value of current I is given by

$$I = \frac{V}{R} = \frac{12}{3} = 4\ \mathbf{A} \qquad \textbf{Ans.}$$

Prob.2. Reduce the network of fig. 1.14 to obtain the equivalent resistance as seen between nodes ad.

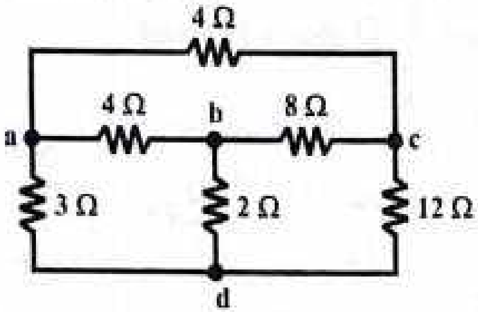


Fig. 1.14 *(R.G.P.V., Dec. 2015)*

Sol. Resistances 4 and 2 ohms are in parallel (fig. 1.14), i.e.

$$= \frac{4 \times 2}{4+2} = \frac{8}{6} = \frac{4}{3}\Omega$$

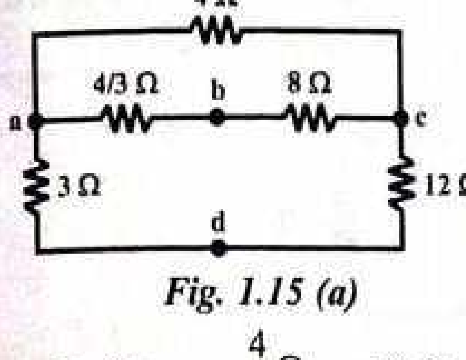


Fig. 1.15 (a)

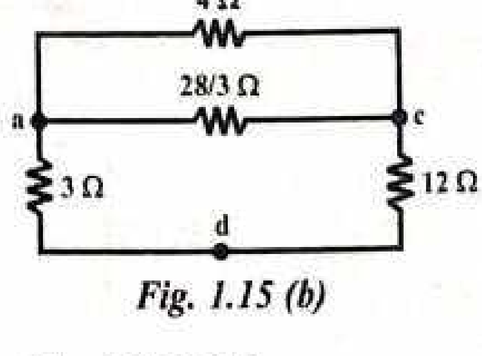


Fig. 1.15 (b)

Resistances $\frac{4}{3}\Omega$ and 8 Ω are in series [fig. 1.15 (a)], i.e.

$$= \frac{4}{3} + 8 = \frac{4+24}{3} = \frac{28}{3}\Omega$$

Resistances $\frac{28}{3}\Omega$ and 12 Ω are in parallel [fig. 1.15 (b)], i.e.

$$= \frac{\frac{28}{3} \times 12}{\frac{28}{3} + 12} = \frac{28 \times 12}{28 + 36} = \frac{21}{4}\Omega$$

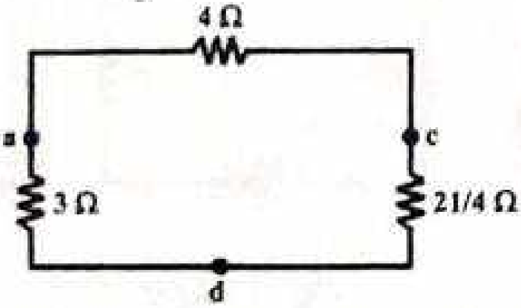


Fig. 1.15 (c)

Resistances 4Ω and $\frac{21}{4}\Omega$ are in series [fig. 1.15 (c)], i.e.

$$= \frac{21}{4} + 4 = \frac{21+16}{4} = \frac{37}{4}\Omega$$

Resistances 3 Ω and $\frac{37}{4}\Omega$ are in parallel [fig. 1.15 (d)] i.e.

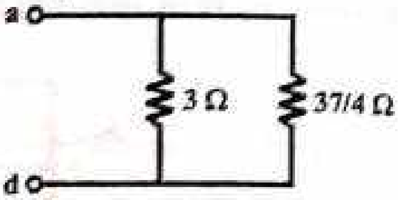


Fig. 1.15 (d)

$$= \frac{3 \times \frac{37}{4}}{3 + \frac{37}{4}} = \frac{3 \times 37}{12 + 37} = \frac{111}{49}\Omega$$

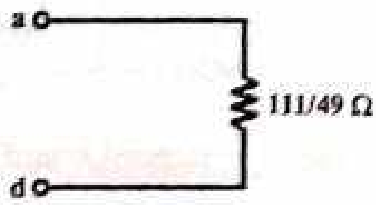


Fig. 1.15 (e)

The equivalent resistance is,

$$R_{eq} = \frac{111}{49}\Omega = 2.26\ \Omega \qquad \text{Ans.}$$

Prob.3. What is the value of unknown resistor R if the voltage drop across the 4Ω resistor is 2V for the circuit shown in fig. 1.16.

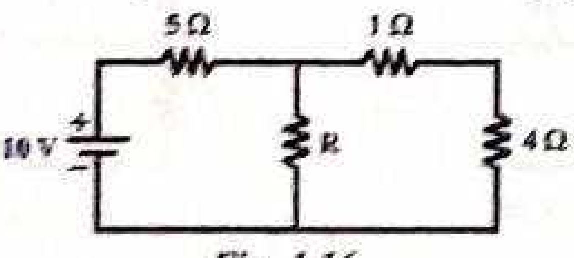


Fig. 1.16

[R.G.P.V., Nov. 2018(O)]

Sol. The given fig. 1.16 can be redrawn as shown in fig. 1.17.

By direct proportion, voltage drop on 1 Ω resistance is

$$= 2 \times \frac{1}{4} = 0.5\ V$$

Drop across CMD or CD = 2 + 0.5 = 2.5 V

Drop across 5 Ω resistance = 10 – 2.5 = 7.5 V

$$I = \frac{7.5}{5} = 1.5\ A$$

$$I_2 = \frac{2}{4} = 0.5\ A$$

$$I_1 = I - I_2 = 1.5 - 0.5 = 1\ A$$

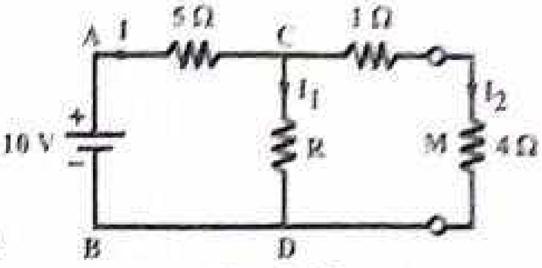


Fig. 1.17

$$1 = \frac{2.5}{R} \text{ or } R = \frac{2.5}{1} = \mathbf{2.5\ \Omega}$$ Ans.

SUPERPOSITION THEOREM, THEVENIN'S THEOREM AND THEIR APPLICATION FOR ANALYSIS OF SERIES AND PARALLEL RESISTIVE CIRCUITS EXCITED BY INDEPENDENT VOLTAGE SOURCES, POWER & ENERGY IN SUCH CIRCUIT

Q.17. State and explain superposition theorem with the help of an example. *(R.G.P.V., June 2009, Dec. 2010, June 2011)*

Or

Explain in brief superposition theorem. *(R.G.P.V., Dec. 2012)*

Or

State and explain superposition theorem. *(R.G.P.V., Dec. 2013)*

Or

State and prove superposition theorem. *(R.G.P.V., May 2019)*

***Ans.* Statement** – Superposition theorem states that "in a linear network containing a several independent sources, the overall response at any point in the network equal the sum of responses due to each independent source considered separately with all other independent sources made in operative. An independent voltage source can be made" in operative by replacing it by a short circuit in the network. Similarly an independent current source can be made inoperative by replacing it by an open circuit.

Proof. Consider a network in which the number of loops are L. Let V_1, V_2, V_3, ... V_L be the voltage sources acting in loops 1, 2, ... L and the loop currents are I_1, I_2, ... I_L.

Thus, the loop equations by using KVL are

$$\begin{array}{ll} \text{Loop 1} & Z_{11}I_1 + Z_{12}I_2 + \dots\dots\dots + Z_{1L}I_L = V_1 \\ \text{Loop 2} & Z_{21}I_1 + Z_{22}I_2 + \dots\dots\dots + Z_{2L}I_L = V_2 \\ \vdots & \vdots \quad\quad \vdots \quad\quad\quad\quad \vdots \quad\quad \vdots \\ \text{Loop L} & Z_{L1}I_1 + Z_{L2}I_2 + \dots\dots\dots + Z_{LL}I_L = V_L \end{array} \quad ...(i)$$

Equation (i) may be written in the form of matrix equation as

$$[Z]\,[I] = [V] \quad ...(ii)$$

$$\text{where,}\quad Z = \begin{bmatrix} Z_{11} & Z_{12}\cdots\cdots Z_{1L} \\ Z_{21} & Z_{22}\cdots\cdots Z_{2L} \\ \vdots & \vdots \qquad\quad \vdots \\ Z_{L1} & Z_{L2}\cdots\cdots Z_{LL} \end{bmatrix},\ [I] = \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_L \end{bmatrix},\ [V] = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_L \end{bmatrix}$$

The solution of equation (ii) may be obtained by using Cramer rule (or by matrix inversion).

Let, ΔZ = Determinant of $[Z]$

ΔZ_{ij} = Co-factor of i^{th} row and j^{th} column of $[Z]$

For $L = 2$, using Cramer rule, the current in the k^{th} loop is given by

$$I_k = \frac{1}{\Delta Z}\left[\Delta Z_{1k} V_1 + \Delta Z_{2k} V_2\right] \quad ...(iii)$$

We assume that the source V_1 acting alone causes a current I_{k1} to flow in the k^{th} loop then equation (iii) becomes

$$I_{k1} = \frac{\Delta Z_{1k} V_1}{\Delta Z} \quad ...(iv)$$

Similarly the current in the k^{th} loop due to source V_2 acting alone,

$$I_{k2} = \frac{\Delta Z_{2k} V_2}{\Delta Z} \quad ...(v)$$

If both the sources are acting simultaneously, then the resultant current in the k^{th} loop will be –

$$I_{k1} + I_{k2} = \frac{1}{\Delta Z}\left[\Delta Z_{1k} V_1 + \Delta Z_{2k} V_2\right] \quad ...(vi)$$

which is equal to I_k. **Hence Proved**

Q.18. Give the various steps to find out the network using superposition theorem.

Ans. Various steps to find out the network using superposition theorem are given as follows –

(i) Take only one independent source of voltage or current and deactivate the other independent voltage or current sources. For voltage sources, remove the source and short circuit the respective circuit terminals and for current sources, just remove the source keeping the respective circuit terminals open. Determine the branch currents.

(ii) Repeat the above step for each of the independent sources.

(iii) To calculate the net branch current utilising superposition theorem, just add the currents obtained in step (i) and step (ii) for each branch. If the currents are in same direction, just add them. While, if the respective currents are directed opposite in each step, consider the direction of the

clockwise current to be positive and subtract the current obtained in the next step from the original current. The net current in each branch is then obtained.

Q.19. Write the limitations of superposition theorem.

Ans. Limitations of superposition theorem are given below –

(i) Superposition theorem cannot be applicable for the non-linear networks or systems.

(ii) During the application of superposition theorem, the direction of currents calculated for each source should be taken care of.

Q.20. State and explain the Thevenin's theorem and find the V_{Th} and R_{Th}. *(R.G.P.V., June 2008, 2009, 2011)*

Or

State Thevenin's theorem giving an example. *(R.G.P.V., Dec. 2012)*

Or

State and explain Thevenin's theorem applicable to electrical circuits. *(R.G.P.V., June 2017)*

Or

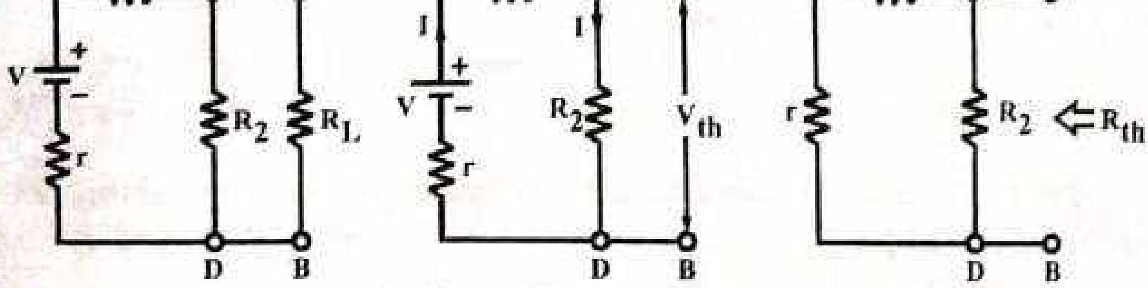
Write short note on Thevenin's theorem. *(R.G.P.V., May 2018)*

Or

State and explain Thevenin's theorem. *[R.G.P.V., Nov. 2018(O)]*

Ans. **Statement** – Thevenin's theorem states that "any linear active network consisting of dependent or independent voltage and current source can be replaced by an equivalent circuit consisting of a voltage source in series with a resistance, the voltage source being the open circuited voltage across the open circuited load terminals and the resistance being the internal resistance of the source network" looking through the open circuited load terminals.

Proof – Suppose that it is required to find out current flowing through load resistance R_L as shown in fig. 1.18 (a).



(a) Network of the Thevenin's Theorem *(b) Network when Load Resistance, R_L Removed* *(c) Network when the Battery V Removed*

Fig. 1.18

First remove the load resistance R_L from the network terminals A and B and then redraw the circuit as shown in fig. 1.18 (b). It is obvious that the terminals

have become open circuited. Determine the open circuit voltage (V_{oc}) or Thevenin's voltage (V_{th}) across the terminals A and B when the load resistance R_L is removed. The Thevenin's voltage (V_{th}) is obtained by the expression as –

$$V_{th} = IR_2 \quad \text{...(i)}$$

$$I = \left[\frac{V}{R_1 + R_2 + r}\right] \quad \text{...(ii)}$$

Then,

$$V_{th} = \left[\frac{V}{R_1 + R_2 + r}\right] R_2 \quad \text{...(iii)}$$

where, I = Current when terminals A and B are open circuited

r = Internal resistance of battery.

Now imagine that the battery to be removed from the network and leaving its internal resistance (r) then redraw the circuit as shown in fig. 1.18 (c). Two parallel paths are viewed from the terminals A and B one containing resistance R_2 and the other containing resistance (R_1 + r). The Thevenin's resistance of the network is determined from the terminals A and B are –

$$R_{th} = R_2 \parallel (R_1 + r) \quad \text{...(iv)}$$

$$R_{th} = \frac{R_2(R_1 + r)}{R_1 + R_2 + r} \quad \text{...(v)}$$

As a consequence shown from terminals A and B, the whole network can be reduced to a single source such as Thevenin's source whose E.M.F., equals to the Thevenin's voltage (V_{th}) and whose internal resistance equal to R_{th} as shown in fig. 1.19.

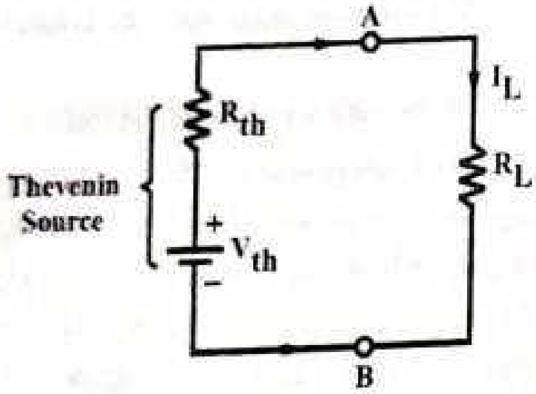


Fig. 1.19 Thevenin's Equivalent Circuit

The load resistance R_L is now connected back across the terminals A and B from where it was previously removed. The current flowing through the load resistance R_L is determined by

$$I_L = \frac{V_{th}}{R_{th} + R_L} \quad \text{....(vi)}$$

Q.21. Explain Thevenin's and superposition theorems giving an application example for each. ***(R.G.P.V., June 2013)***

Ans. Refer the ans. of Q.20 and Q.17.

Q.22. Enlist the various steps to find out the Thevenin's equivalent network.

Ans. Various steps to find out the Thevenin's equivalent are given as follows –

(i) Disconnect the load resistor and find the open circuit voltage across the open circuited load terminals.

(ii) Remove the voltage source by internal resistance (short circuit is placed) and current source by open circuit, and find the internal resistance of the source, which is known as Thevenin's resistance.

(iii) By placing R_{Th} in series with $V_{o.c.}$, find the Thevenin's equivalent circuit.

(iv) Reconnect the load resistor (R_L) across the load terminals as shown in fig. 1.20.

Obviously I_L (the load current)

$$= \frac{V_{o.c.}}{R_{th} + R_L}$$

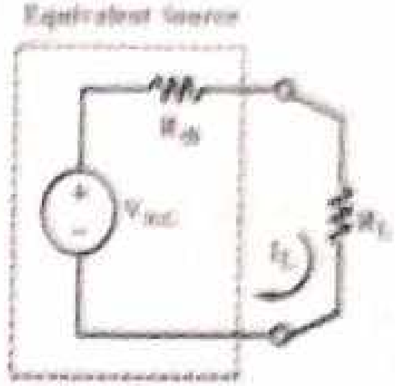
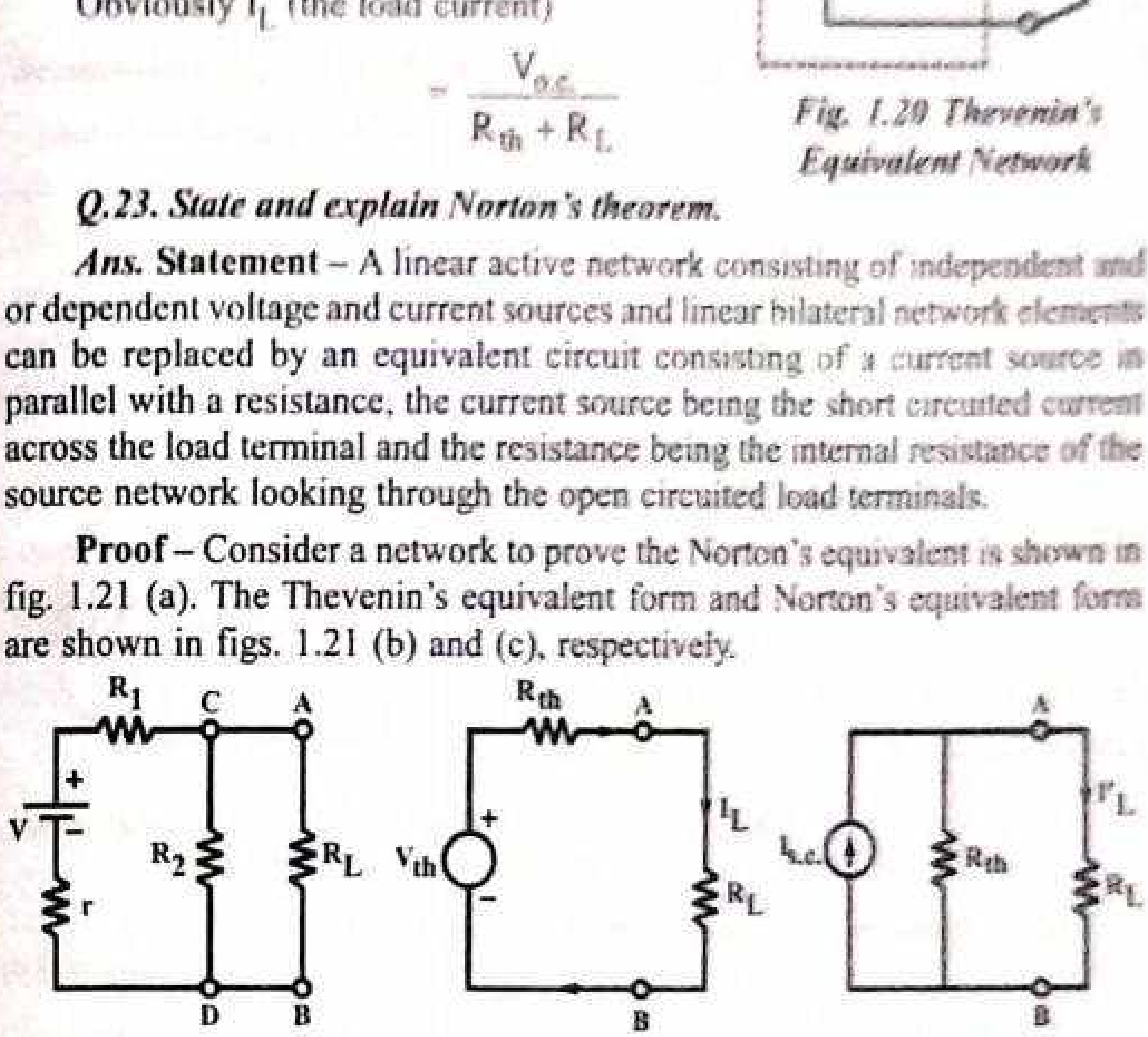


Fig. 1.20 Thevenin's Equivalent Network

Q.23. State and explain Norton's theorem.

Ans. **Statement** – A linear active network consisting of independent and or dependent voltage and current sources and linear bilateral network elements can be replaced by an equivalent circuit consisting of a current source in parallel with a resistance, the current source being the short circuited current across the load terminal and the resistance being the internal resistance of the source network looking through the open circuited load terminals.

Proof – Consider a network to prove the Norton's equivalent is shown in fig. 1.21 (a). The Thevenin's equivalent form and Norton's equivalent form are shown in figs. 1.21 (b) and (c), respectively.



(a) Network of the Norton's Theorem *(b) Thevenin's Equivalent Form of the Given Network* *(c) Norton's Equivalent Form of the Given Network*

Fig. 1.21

The current through the load resistance R_L into the Thevenin's equivalent circuit is determined by

$$I_L = \frac{V_{th}}{R_{th} + R_L} \qquad ...(i)$$

On short circuiting terminals A and B then we obtain the short circuit current $I_{s.c.}$ as

$$I_{s.c.} = V_{th} / R_{th} \qquad ...(ii)$$

In the Norton's equivalent circuit, the current through the load resistance R_L is given as

$$I_L' = \frac{I_{s.c.} R_{th}}{R_{th} + R_L} = \frac{(V_{th}/R_{th})(R_{th})}{(R_{th} + R_L)} \quad ...(iii)$$

or

$$I_L' = \frac{V_{th}}{R_{th} + R_L} \quad ...(iv)$$

Therefore the value of the load current into the Norton's equivalent circuit, I_L' is equal to the load current which is measured from the Thevenin's equivalent circuit.

Q.24. Write down the various steps to find out the Norton's equivalent network.

Ans. Various steps to find out the Norton's equivalent are given as follows –

(i) Remove the load resistor and find the internal resistance of the source network by deactivating the constant sources. This procedure is exactly same as described for Thevenin's theorem. Assume that this resistance be R_{int}.

(ii) Now, short the load terminals and find the short circuit current flowing through the shorted load terminals using conventional network analysis. Assume that this current be $i_{s.c}$.

(iii) Norton's equivalent circuit is drawn by keeping R_{int} in parallel to $i_{s.c.}$ as shown in fig. 1.22.

(iv) Reconnect the load resistor (R_L) across the load terminals and the current through it (I_L) is then defined as

$$I_L = i_{s.c.} \frac{R_{int}}{R_{int} + R_L}$$

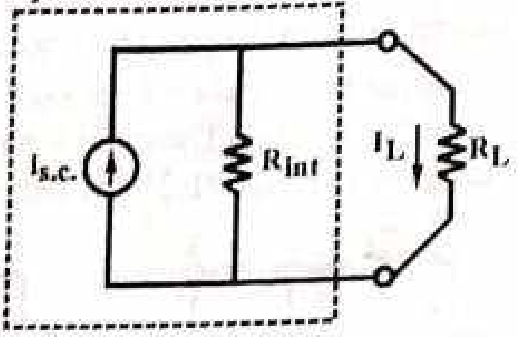


Fig. 1.22 Norton's Equivalent Circuit

Q.25. Differentiate between the series and parallel circuits.
(R.G.P.V., June 2009)

Ans. In a series circuit (fig. 1.23), the current being same through each of the impedances, the voltage phasors are related to the current by the respective drops across each impedance vectorially added together.

i.e.,
$$V = IZ_1 + IZ_2 + IZ_3 + ... + Z_n = IZ_{eq} \quad ...(i)$$

where Z_{eq} = Equivalent impedance = $Z_1 + Z_2 + ...Z_n$

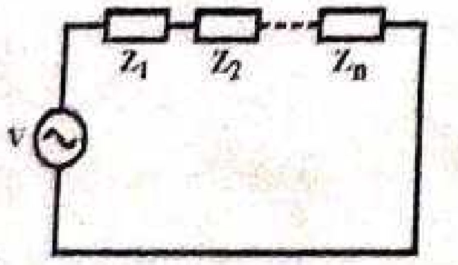


Fig. 1.23 Series A.C. Circuit

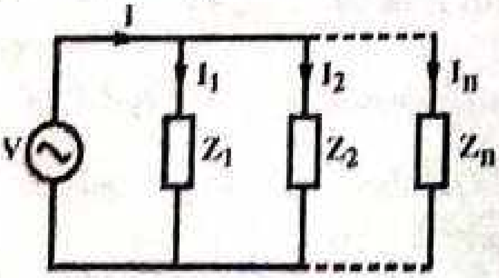


Fig. 1.24 Parallel A.C. Circuit

On the other hand, in a parallel circuit (fig. 1.24), the voltage drop across each element being same, the currents through each branch are different, the branch currents are to be vectorially added to give the total current.

i.e., $$I_1 = \frac{V}{Z_1} = VY_1, I_2 = \frac{V}{Z_2} = VY_2 \text{ and so on,} \qquad \left[\because Y_1 = \frac{1}{Z_1}\right]$$

i.e., $$I = I_1 + I_2 + ... + I_n$$

or $$VY_{eq} = VY_1 + VY_2 + ... + VY_n$$
$$= V(Y_1 + Y_2 + Y_3 + ... + Y_n)$$

i.e., $$Y_{eq} = Y_1 + Y_2 + ... + Y_n \qquad ...(ii)$$

Q.26. Define the following terms –

(i) Electrical energy

(ii) Electrical power.

Ans. (i) Electrical Energy – If a potential difference V is applied across a circuit, a current I flows through it for a particular period t (in sec), as shown in fig. 1.25.

A work is said to be done by moving stream of electrons (or charge). This work is called electrical energy. Therefore, the total amount of work done in an electrical circuit is known as electrical energy and the unit of electrical energy is joule (W-sec).

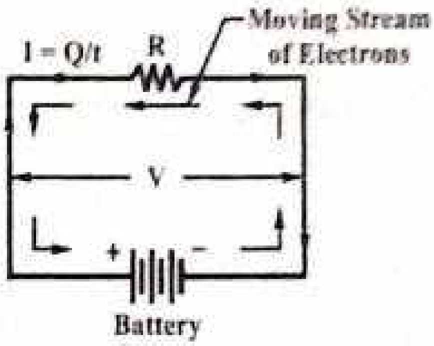


Fig. 1.25

$$V = \frac{\text{Work done}}{Q}$$

Thus, work done or electrical energy is expressed as –

$$= V.Q \qquad [\because I = Q/t]$$
$$= V.It \qquad [\because V = IR]$$
$$= IR.It = I^2Rt$$
$$= \frac{V^2}{R}t$$

(ii) Electrical Power – The rate at which work is being done in an electrical circuit is known as electrical power. It is denoted by P and an unit of electrical power is watt.

Therefore, $$P = \frac{\text{Work done in electrical circuit}}{\text{Time}}$$
$$= \frac{VIt}{t} = VI$$
$$= IR.I = I^2R = \frac{V^2}{R}$$

NUMERICAL PROBLEMS

Prob.4. Using superposition theorem, determine the current in 5 ohm resistance.

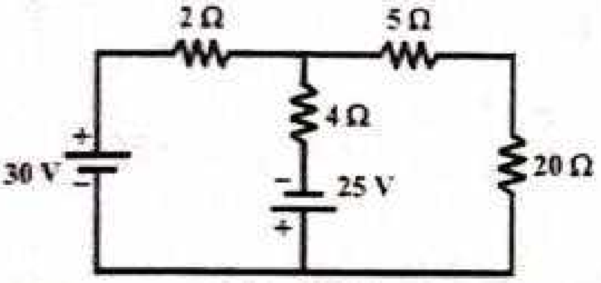


Fig. 1.26

(R.G.P.V., Dec. 2008, June 2017)

Sol. Considering the voltage source 30 V alone and short circuiting the voltage source 25 V, the network reduces to form shown in fig. 1.27 (a).

The total resistance of the network to the source 30 V is,

$$R'_1 = 2 + [(5 + 20) \parallel 4]$$

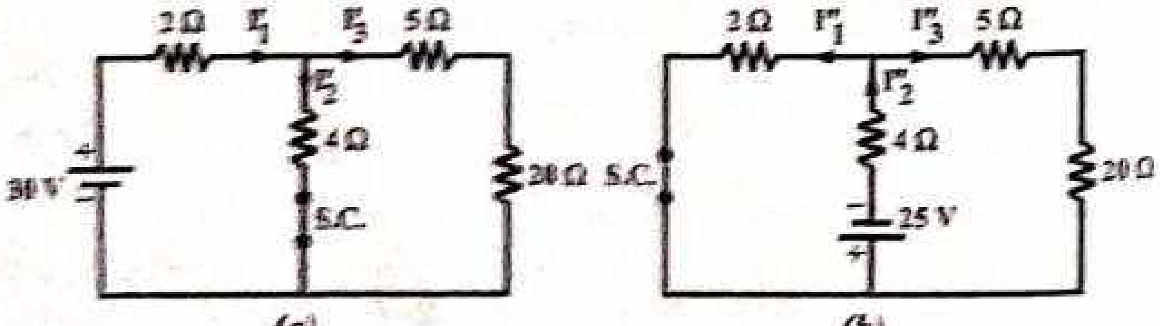
$$= 2 + \frac{25 \times 4}{25 + 4} = 5.45\ \Omega$$

Hence the current I'_1 is

$$I'_1 = \frac{30}{5.45} = 5.5\ \text{A}$$

Then, $$I'_2 = 5.5 \times \left(\frac{5+20}{4+5+20}\right) = 4.74\ \text{A}$$

Now, $$I'_3 = I'_1 - I'_2 = 5.5 - 4.74 = 0.76\ \text{A}$$



(a) *(b)*

Fig. 1.27

Now considering the voltage source 25 V alone and short circuiting the voltage source 30 V, the network reduces to form shown in fig. 1.27 (b).

Total resistance of the network to source 25 V is

$$R''_1 = (25 \parallel 2) + 4 = \frac{25 \times 2}{25 + 2} + 4 = 5.852\ \Omega$$

Hence $$I''_2 = \frac{25}{5.852} = 4.272\ \text{A}$$

Now, $$I''_1 = 4.272 \times \left(\frac{5+20}{2+5+20}\right) = 3.96 \text{ A}$$

$\therefore$ $$I''_3 = I''_2 - I''_1 = 4.272 - 3.96 = 0.312 \text{ A}$$

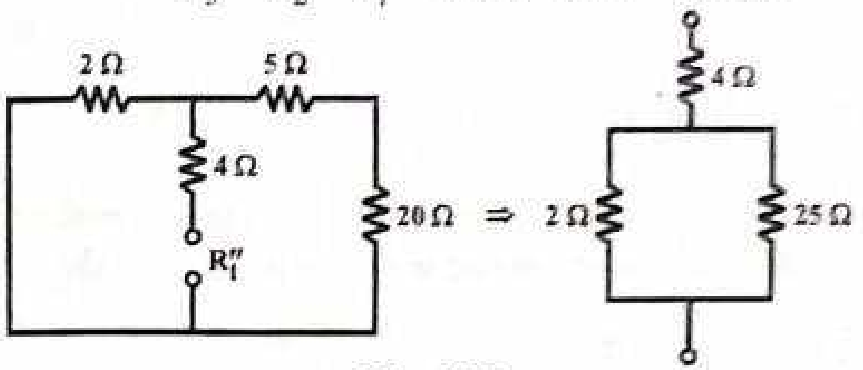


Fig. 1.28

When both source voltages 30 V and 25 V are considered, then by superposition theorem,

$$I_1 = I'_1 - I''_1 = 5.5 - 3.96 = 1.54 \text{ A}$$
$$I_2 = I'_2 - I''_2 = 4.74 - 4.272 = 0.468 \text{ A}$$
$$I_3 = I'_3 + I''_3 = 0.76 + 0.312 = \mathbf{1.072\ A}$$ **Ans.**

Where, I_3 is the current flowing through the resistance 5 Ω.

Prob.5. State superposition theorem. In the given network, making use of superposition theorem, determine the currents in resistors R_1, R_2 and R_3 and also the currents in voltage source E.

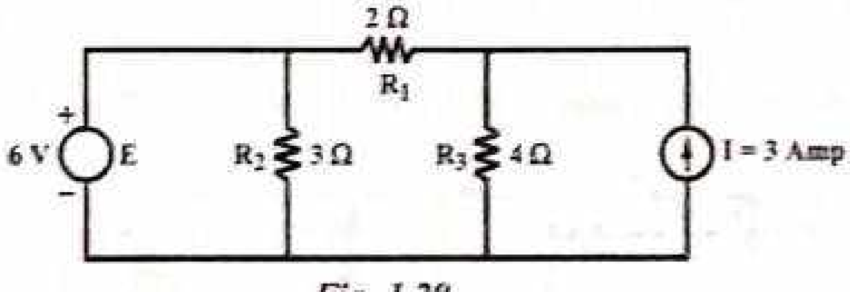


Fig. 1.29

(R.G.P.V., Dec. 2011)

***Sol.* Superposition Theorem** – Refer the ans. of Q.17.

Considering the voltage source E alone and open circuiting the current source I, the network reduces to that is shown in fig. 1.30 (a).

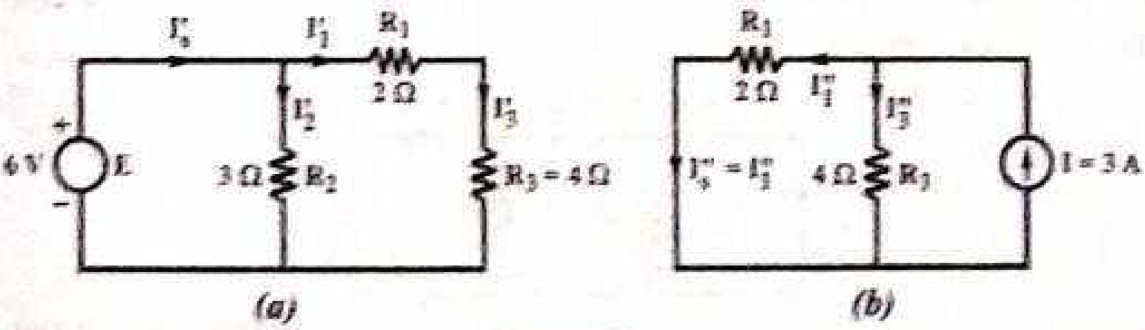


Fig. 1.30

Then

$$I'_2 = \frac{6 \text{ volts}}{3 \text{ ohms}} = 2 \text{ A}$$

$$I'_1 = I'_3 = \frac{6 \text{ volts}}{6 \text{ ohms}} = 1 \text{ A}$$

The current drawn from voltage source is,

$$I'_s = I'_1 + I'_2 = (1 + 2) = 3 \text{ A}$$

Next considering the current source I alone and short circuiting the voltage source E, the network reduces to that is shown in fig. 1.30 (b).

Then current $$I''_1 = I.\frac{4}{4+2} = \frac{3 \times 4}{6} = 2 \text{ A}$$

$$I''_3 = I \times \frac{2}{4+2} = \frac{3 \times 2}{6} = 1 \text{ A}$$

Current through R_2 is zero since a short circuit has been placed across it.

Current through voltage source, $I''_1 = 2$ A

When both the sources are considered, then by superposition theorem,

$$I_1 = I'_1 - I''_1 = (1 - 2) = -1 \text{ A} \qquad \textbf{Ans.}$$

Hence 1 A current flows through R_1 from right to left,

$$I_2 = I'_2 + 0 = 2 \text{ A} \qquad \textbf{Ans.}$$

$$I_3 = I'_3 + I''_3 = 1 + 1 = 2 \text{ A} \qquad \textbf{Ans.}$$

Current through voltage source is,

$$I_s = I'_s - I''_s = 3 - 2 = 1 \text{ A} \qquad \textbf{Ans.}$$

Hence current distribution in the network is shown in fig. 1.30 (c).

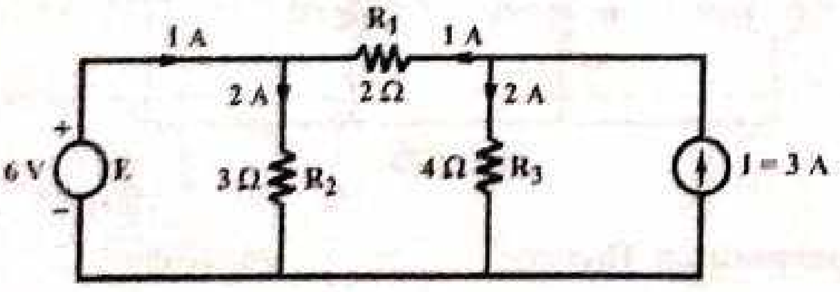


Fig. 1.30 (c)

Prob.6. Find Thevenin's equivalent circuit between terminals A and B for the circuit shown in fig. 1.31.

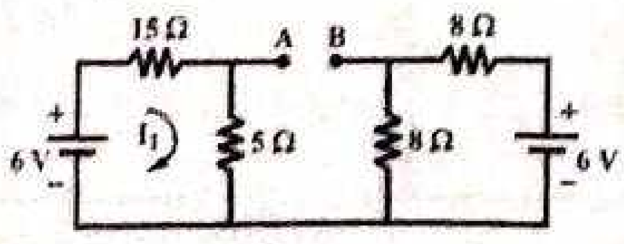


Fig. 1.31 ***(R.G.P.V., Dec. 2016)***

Sol. The given circuit is redrawn to find the Thevenin's equivalent circuit, as shown in fig. 1.32.

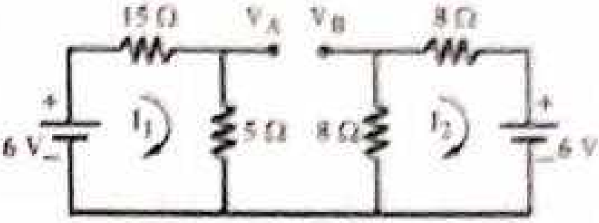


Fig. 1.32

Let I_1 and I_2 be the mesh currents as shown in fig. 1.32. Then mesh currents are –

$$I_1 = \frac{6}{15+5} = \frac{6}{20} = 0.3 \text{ A}$$

and
$$I_2 = \frac{-6}{8+8} = -0.375 \text{ A}$$

Writing KVL equation in the central loop, we obtain

$$V_A + 5\,I_1 + 8\,I_2 = V_B$$
$$V_A + 5 \times 0.3 + 8 \times (-0.375) = V_B$$
$$V_A - 1.5 = V_B$$

Therefore,
$$V_{o.c.} = V_{AB} = 1.5 \text{ V}$$

To find R_{th}, we replace all the two sources by short circuits as shown in fig. 1.33.

$$\therefore \qquad R_{th} = \frac{15 \times 5}{15+5} + \frac{8 \times 8}{8+8} = 3.75 + 4 = 7.75\ \Omega = 31/4\ \Omega$$

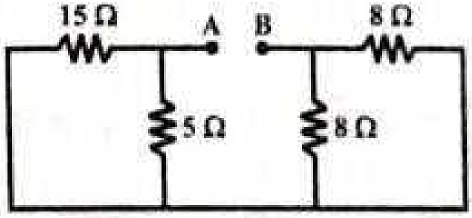


Fig. 1.33

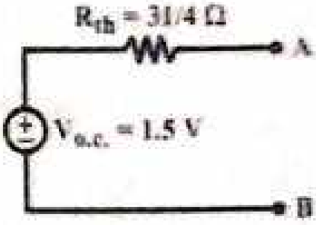


Fig. 1.34

The Thevenin's equivalent circuit is shown in fig. 1.34.

Prob.7. State Thevenin's theorem and explain procedure to apply Thevenin's theorem. Using this theorem find the current in resistance R_L shown in fig. 1.35.

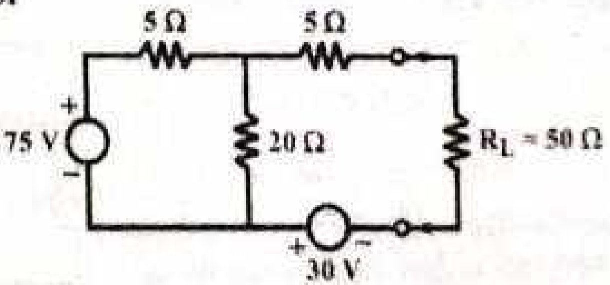


Fig. 1.35

(R.G.P.V., Dec. 2015)

Sol. Refer the ans. of Q.20 and Q.22.

The given circuit can be redrawn as shown in fig. 1.36 with the 50 Ω resistor removed from the terminals a and b to find out $V_{o.c.}$ or V_{th}.

For this purpose, we will go from point b to point a and find the algebraic sum of the voltages met on the way. It is clear that with terminals a and b open, there is no voltage drop on the 5 Ω resistance. Therefore the two resistances of 5 Ω and 20 Ω are connected in series across the 75 V battery. According to voltage divider formula, voltage drop on 20 Ω resistance

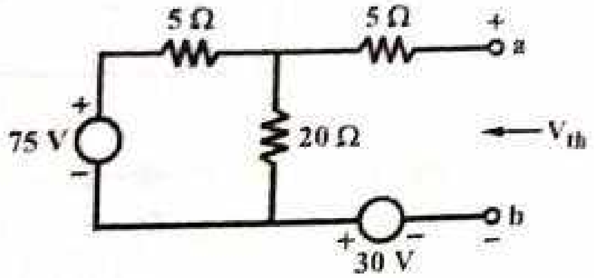


Fig. 1.36

$$= 75 \times \frac{20}{20+5} = 75 \times \frac{20}{25} = 60 \text{ V}$$

$$\therefore \qquad V_{th} = V_{ab} = 60 - 30 = 30 \text{ volt}$$

We will find R_{th} i.e. Thevenin's resistance of the network as looked back into the open circuited terminals a and b for this, we will replace voltage by short circuit as shown in fig. 1.37.

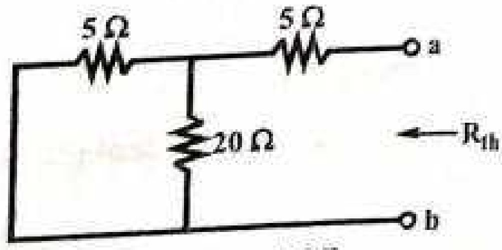


Fig. 1.37

Here, $$R_{th} = \frac{5 \times 20}{5+20} + 5 = \frac{100}{25} + 5 = 4 + 5 = 9 \, \Omega$$

Now, we draw the Thevenin's equivalent circuit as shown in fig. 1.38.

Hence the current flowing through the resistor 50 Ω is given by

$$I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{30}{9+50}$$

$$= \mathbf{0.51 \text{ A}} \qquad \textbf{Ans.}$$

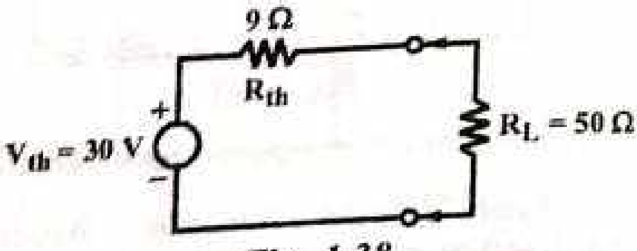


Fig. 1.38

Prob.8. Using Thevenin's theorem find the current flowing through 6 Ω resistor of the network shown in fig. 1.39. ***(R.G.P.V., Dec. 2012)***

Sol. When 6 Ω resistor is removed, whole of 2 A current flows along D.C. producing a drop of (2 × 2) = 4 V with the polarity as shown in fig. 1.40.

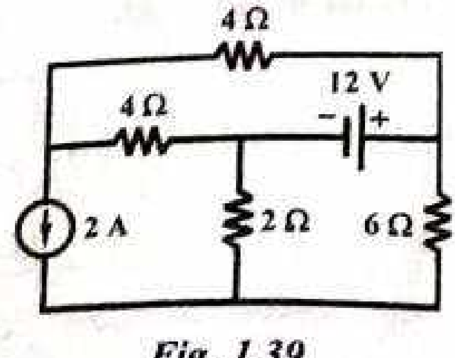


Fig. 1.39

Since we go along BCDA, the total voltage is

$$= -4 + 12 \text{ V} = 8 \text{ V}$$

Hence $\qquad V_{o.c.} = V_{th} = 8 \text{ V}$

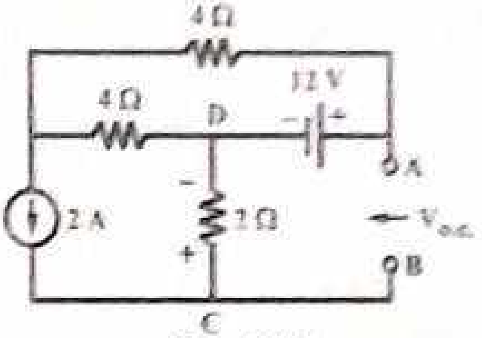


Fig. 1.40

For finding R_{th}, 12 V voltage source is replaced by a short circuit, and the 2 A current source by an open circuit, as shown in fig. 1.41.

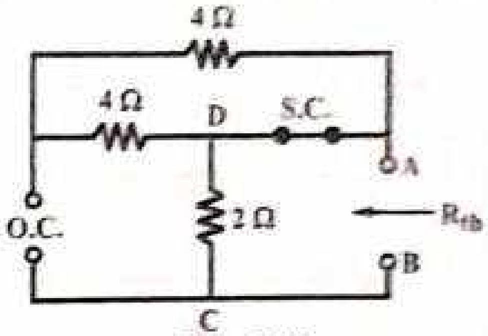


Fig. 1.41

The two 4 Ω resistors are in series and are thus equivalent to an 4 + 4 = 8 Ω resistor. Although, this 8 Ω resistor is in parallel with a short of 0 Ω. As a result, them equivalent value is 0 Ω. Now this 0 Ω resistance is in series with the 2 Ω resistor. Then, we get

$$R_{th} = 2 + 0 = 2\ \Omega$$

Now, the Thevenin's equivalent circuit is shown in fig. 1.42.

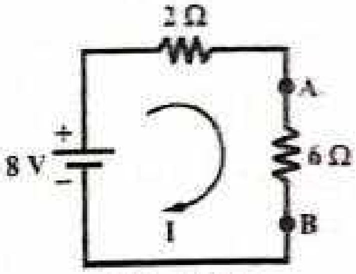


Fig. 1.42

$$I = \frac{V_{th}}{R_{th} + R_L} = \frac{8}{2+6} = 1 \text{ A} \quad \textbf{Ans.}$$

Prob.9. State Thevenin's theorem. Determine the current through a 3Ω resistor branch in the circuit using Thevenin's theorem.

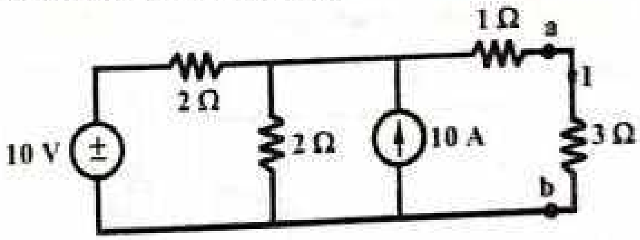


Fig. 1.43

(R.G.P.V., Dec. 2014)

***Sol.* Thevenin's Theorem** – Refer to the ans. of Q.20.

The given circuit can be redrawn with the 3 Ω resistor removed from terminals a and b. The current source has been converted into its equivalent voltage source to findout $V_{o.c.}$ or V_{th} as shown in fig. 1.44.

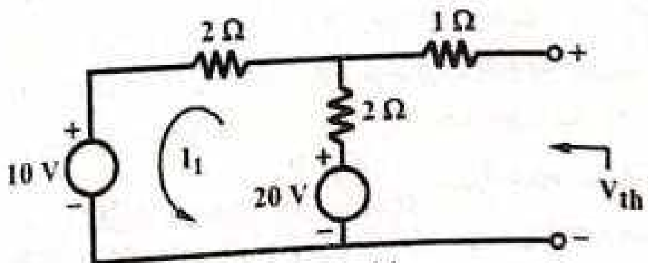


Fig. 1.44

The circulating current I_1 can be calculated as

$$-10 + 20 - 2I_1 - 2I_1 = 0$$

$$I_1 = \frac{10}{4} = 2.5 \text{ A}$$

Now, $$V_{o.c.} = V_{th} = +20 - 2(2.5) = 20 - 5 = 15 \text{ V}$$

We will find R_{th} i.e., equivalent resistance of the network as looked back into the open circuited terminals a and b. For this, we will replace voltage source by short circuit as shown in fig. 1.45 (a).

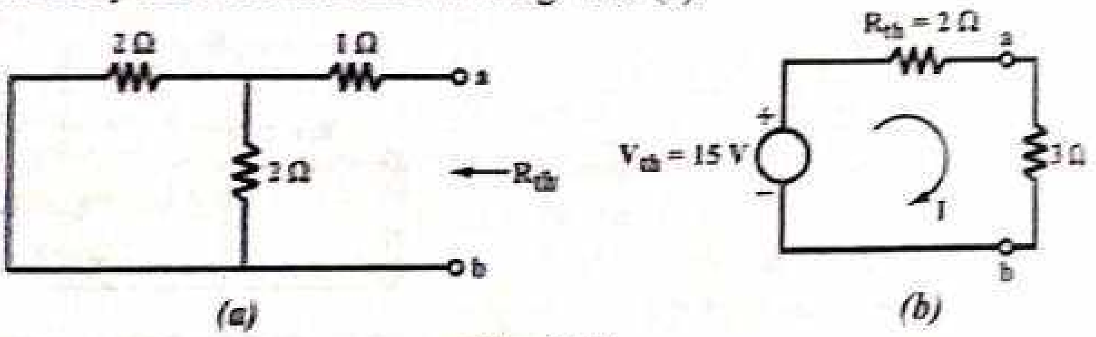


Fig. 1.45

Here, $$R_{th} = \frac{2 \times 2}{2 + 2} + 1 = 1 + 1 = 2\ \Omega$$

Now, we draw the Thevenin's equivalent circuit [fig. 1.45 (b)].

Hence, current flowing through the resistor 3 Ω is

$$I = \frac{V_{th}}{R_{th} + R_L} = \frac{15}{2 + 3} = \frac{15}{5} = 3 = 3 \text{ A} \qquad \textbf{Ans.}$$

Prob.10. State the Norton's theorem. In the circuit below determine –

(i) The value of R so that the load of 20 ohm draws maximum power

(ii) The value of maximum power drawn by the load.

(R.G.P.V., June 2012)

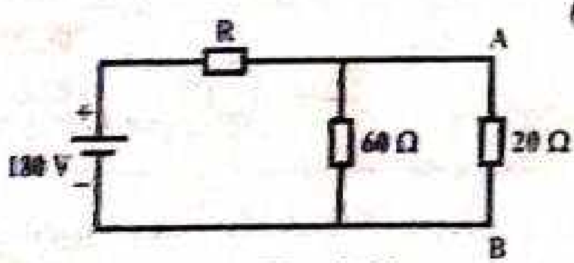


Fig. 1.46

Sol. Norton's Theorem – Refer the ans. of Q.23.

The load of 20 Ω will draw maximum power when internal resistance of network R_T when viewed from output terminals A and B is minimum and it will be minimum when R is zero.

(i) So R = 0 **Ans.**

(ii) Maximum power drawn

$$= \frac{V^2}{R_L} = \frac{(180)^2}{20} = \mathbf{1620\ W} \qquad \textbf{Ans.}$$

Prob.11. *In the circuit of fig. 1.47, find the power in R_L utilizing Thevenin's theorem.*

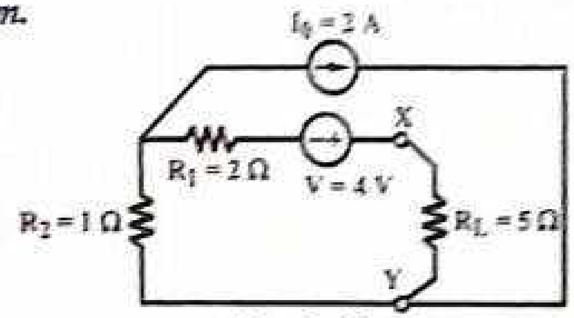


Fig. 1.47

Sol. First calculate the open circuit voltage $V_{o.c.}$ or V_{th} across the open circuited X-Y terminals (in fig. 1.48) and R_L be removed.

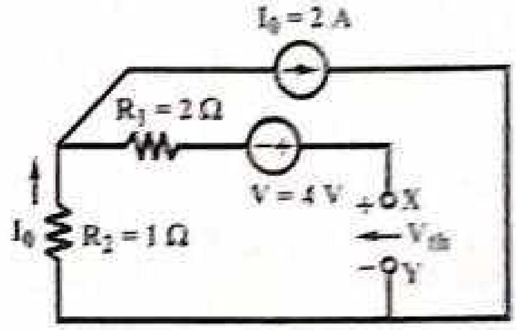


Fig. 1.48

Here, $V_{o.c.} = V_{th}$

$$= V - I_0R_2 = 4 - 2 \times 1 = 2\ V$$

To find R_{th}, all the constant sources are removed (i.e., V = 0, I_0 = 0). Fig. 1.49 represents the required circuit.

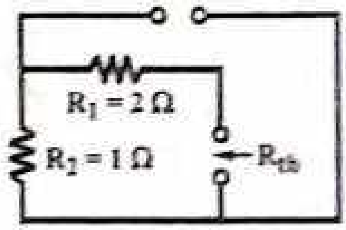


Fig. 1.49

Clearly,

$$R_{th} = R_1 + R_2 = 2 + 1 = 3\ \Omega$$

Therefore, we have obtained the equivalent Thevenin's circuit as shown in fig. 1.50.

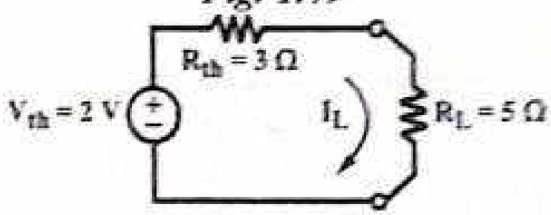


Fig. 1.50

Here,

$$V_{o.c.} = V_{th} = 2\ V$$

$$R_{th} = R_{int} = 3\ \Omega$$

The load current is given by

$$I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{2}{3+5} = \frac{1}{4} = \mathbf{0.25\ A} \qquad \textbf{Ans.}$$

Power P in $R_L = I_L^2 R_L = (0.25)^2 \times 5 = \mathbf{0.3125\ watt}$ **Ans.**

MESH & NODAL ANALYSIS, STAR DELTA TRANSFORMATION & CIRCUITS

Q.27. *Explain the mesh current or loop current method in brief.*
(R.G.P.V., June 2007)

Ans. In this method, a current is assigned to each window of the network such that the currents complete a closed loop. They are also known as loop currents. When a branch has two of the mesh currents, the actual current given

by their algebraic sum. The assigned mesh currents may have either clockwise or counter clockwise directions. Once the currents are assigned, Kirchhoff's voltage law is written for each loop to obtain the necessary simultaneous equations.

Q.28. State and explain mesh analysis to solve a network.

(R.G.P.V., Dec. 2008)

Ans. Mesh analysis algorithm is given below and is explained through the simple circuit of fig. 1.51.

(i) Identify independent circuit meshes. There are two such meshes in the circuit of fig. 1.51.

(ii) Assign a circulating current to each mesh (I_1, I_2 in fig. 1.51). As each mesh current enters as well as leaves the mesh elements, the mesh currents implicitly satisfy KCL. It is preferable to assign the same direction to the mesh currents – usually clockwise.

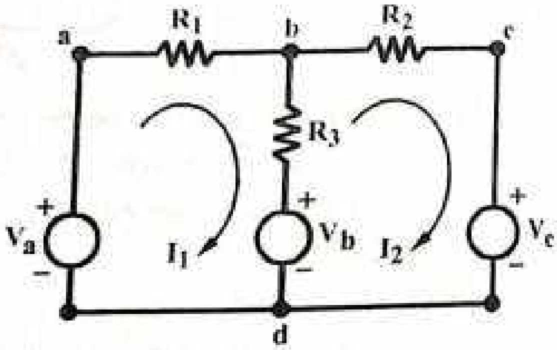


Fig. 1.51

(iii) Write KVL equations for each mesh (as many as mesh currents). It is observed here that no circuit branch can carry more than two mesh currents.

(iv) It is assumed that all circuit sources are voltage sources. Practical current sources, if any are first converted to equivalent voltage sources.

Let us write KVL equations for the two meshes of fig. 1.51.

$$\text{Mesh 1} : R_1I_1 + R_3(I_1 - I_2) + V_b - V_a = 0 \quad ...(i)$$

$$\text{Mesh 2} : R_3(I_2 - I_1) + R_2I_2 + V_c - V_b = 0 \quad ...(ii)$$

These equations can be organized in the form below –

$$\text{Mesh 1} : (R_1 + R_3)I_1 - R_3I_2 = V_a - V_b \quad ...(iii)$$

$$\text{Mesh 2} : - R_3I_1 + (R_2 + R_3)I_2 = V_b - V_c \quad ...(iv)$$

Equations (iii) and (iv) can be written in the matrix form –

$$\begin{bmatrix} (R_1 + R_3) & -R_3 \\ -R_3 & (R_2 + R_3) \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} (V_a - V_b) \\ (V_b - V_c) \end{bmatrix}$$

or $$[R]\ [I] = [V]$$

where [R] = Mesh resistance matrix

[I] = Mesh currents vector

[V] = Vector of algebraic sum of voltages of all voltage sources round the loop.

Q.29. Explain the node voltage method in brief.

Ans. In this method, one of the principal nodes is selected as the reference and equations based on KCL are written at the other principal nodes. At each of these other principal nodes, a voltage is assigned where it is understood that this is a voltage with respect to the reference node. These voltages are the unknowns and when determined by a suitable method, result in the network solution.

Q.30. Explain node analysis method with the help of an example.

Or

Explain the nodal analysis with suitable example.

[R.G.P.V., Nov. 2018(O)]

Ans. To determine the equilibrium equation on the node basis we make use of the Kirchhoff's current law (KCL). Let us consider the simple resistive network to represent the procedure used in node analysis as shown in fig. 1.52. There are four nodes, namely (1), (2), (3) and (4). For a convenience, the negative terminal of an active element is selected as the reference node, we select node (4) as the reference node and assume its potential to be zero.

A potential difference between any two nodes in a network is called the node pair voltage. Thus V_{12}, V_{23}, V_{31}, V_{14},V_{24} and V_{34} are the node pair voltages. However, the potential of a particular node with respect to the reference node is termed the node voltage. Hence, V_{14}, V_{24} and V_{34} are the node voltages.

With reference to fig. 1.52, the node voltage V_{14} is known to be equal to the battery voltage. Having identified the unknown voltages, our next aim is to write network equations in terms of these unknown voltages.

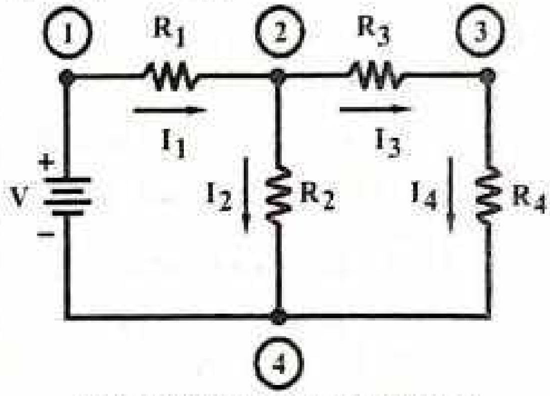


Fig. 1.52 Simple Resistive Network for Node Analysis

Let the node voltages of nodes (1), (2) and (3) be called V_1, V_2 and V_3 respectively.

Applying KCL at node (2), we have

$$I_1 - I_2 - I_3 = 0 \quad ...(i)$$

These branch currents are expressed in terms of node voltages by Ohm's law as –

$$I_1 = \frac{1}{R_1}(V_2 - V_1) = \frac{1}{R_1}(V_2 - V) \quad ...(ii)$$

$$I_2 = \frac{1}{R_2}(V_2 - 0) = \frac{V_2}{R_2} \quad ...(iii)$$

and,

$$I_3 = \frac{V_2 - V_3}{R_3} \quad ...(iv)$$

On substituting the values of I_1, I_2 and I_3 from equations (ii), (iii) and (iv) into equation (i), we get

$$\frac{V_2 - V}{R_1} - \frac{V_2}{R_2} - \frac{V_2 - V_3}{R_3} = 0$$

or

$$\frac{V_2}{R_1} - \frac{V}{R_1} - \frac{V_2}{R_2} - \frac{V_2}{R_3} + \frac{V_3}{R_3} = 0$$

or $$\left(\frac{1}{R_1} - \frac{1}{R_2} - \frac{1}{R_3}\right)V_2 + \frac{V_3}{R_3} = \frac{V}{R_1} \qquad \text{...(v)}$$

Now applying KCL at node (3) we have

$$I_3 = I_4$$

or $$I_3 - I_4 = 0 \qquad \text{...(vi)}$$

Since, $$I_3 = \frac{V_2 - V_3}{R_3} \text{ and } I_4 = \frac{V_3 - 0}{R_4} = \frac{V_3}{R_4}$$

Substituting the values of I_3 and I_4 into equation (vi), we have

$$\frac{V_2}{R_3} - \left(\frac{1}{R_3} + \frac{1}{R_4}\right)V_3 = 0 \qquad \text{...(vii)}$$

To obtain the values of V_2 and V_3, solved the equations (v) and (vii) simultaneously. Thus, it is clear that the positive direction of the branch currents may be assumed at each node independent of their previous designations. There are two options as follows –

(i) Assume positive directions for branch current once for all

(ii) Assume new positive directions at each node.

Q.31. State and explain Kirchhoff's law with suitable example.
(R.G.P.V., June 2016)

Ans. Refer the ans. of Q.16, Q.28 and Q.30.

Q.32. What do you mean by delta and star connections ?

Ans. When three resistances R_1, R_2 and R_3 are connected together to form a closed mesh as shown in fig. 1.53, this type of connection of resistances is called delta connection.

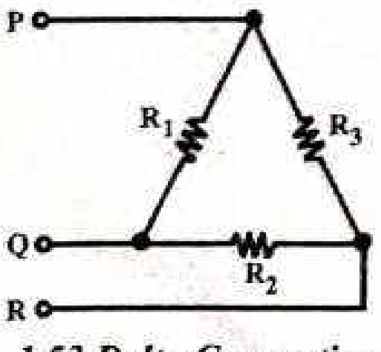


Fig. 1.53 Delta Connection

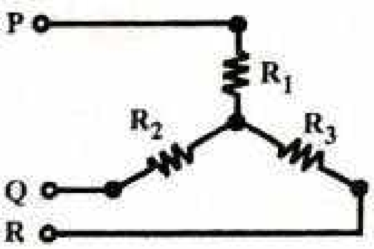


Fig. 1.54 Star Connection

If three resistances R_1, R_2 and R_3 are connected as per fig. 1.54, the connection of resistance is called star connection.

Q.33. Derive the necessary equations for converting a delta network into an equivalent star network. ***(R.G.P.V., July 2008, Feb. 2010)***

Ans. We assume the terminals P, Q and R in fig. 1.55.

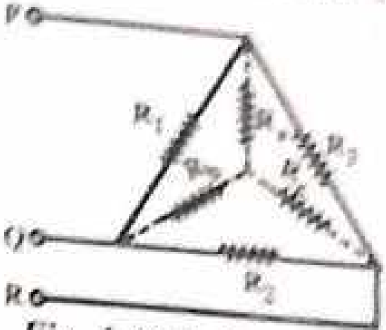


Fig. 1.55 Delta to Star Transformation

With the terminal Q open, series combination of resistances R_1 and R_2 is in parallel with R_3.

$\therefore$ R_{PR} (when terminal Q is open) is given by

$$= \frac{R_3(R_1+R_2)}{R_1+R_2+R_3}$$

Resistances between terminals P and R with Q terminal open in fig. 1.55 with star connection.

$$R_{PR} = R_a + R_c$$

For these two networks to be electrically equivalent,

$$R_a + R_c = \frac{R_3(R_1+R_2)}{R_1+R_2+R_3} \quad ...(i)$$

$$R_a + R_b = \frac{R_1(R_2+R_3)}{R_1+R_2+R_3} \quad ...(ii)$$

and $$R_b + R_c = \frac{R_2(R_1+R_3)}{R_1+R_2+R_3} \quad ...(iii)$$

By solving the equations (i), (ii) and (iii), we get

$$R_a = \frac{R_1R_3}{R_1+R_2+R_3}, R_b = \frac{R_1R_2}{R_1+R_2+R_3} \text{ and } R_c = \frac{R_2R_3}{R_1+R_2+R_3}$$

Q.34. Deduce the relation for conversion from star to delta circuit.

(R.G.P.V., Dec. 2006, April 2009)

Ans. Star connected network as shown in fig. 1.56 will be replaced by equivalent delta connected network. The basic equations guiding this conversion are

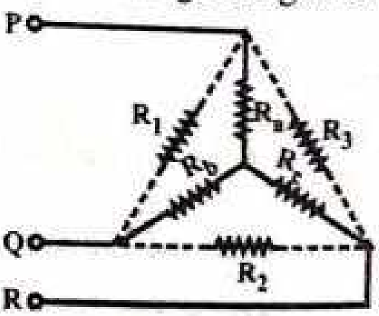


Fig. 1.56 Star to Delta Transformation

$$R_a + R_c = \frac{R_3(R_1+R_2)}{R_1+R_2+R_3} \quad ...(i)$$

$$R_b + R_a = \frac{R_1(R_2+R_3)}{R_1+R_2+R_3} \quad ...(ii)$$

and $$R_b + R_c = \frac{R_2(R_1+R_3)}{R_1+R_2+R_3} \quad ...(iii)$$

By solving the equations (i), (ii) and (iii), we get

$$R_a = \frac{R_1R_3}{R_1+R_2+R_3} \quad ...(iv)$$

$$R_b = \frac{R_1R_2}{R_1 + R_2 + R_3}$$

$$R_c = \frac{R_2R_3}{R_1 + R_2 + R_3}$$

Dividing equation (vi) by (iv), we get

$$\frac{R_c}{R_a} = \frac{R_2}{R_1} \quad \text{or} \quad R_2 = \frac{R_c}{R_a} \times R_1$$

Again, dividing equation (vi) by (v), we get

$$\frac{R_c}{R_b} = \frac{R_3}{R_1} \quad \text{or} \quad R_3 = \frac{R_c}{R_b} \times R_1$$

Substituting the values of R_2 and R_3 in equation (iv), we get

$$R_a = \frac{R_1 \times R_1 \times \dfrac{R_c}{R_b}}{R_1 + R_1 \times \dfrac{R_c}{R_a} + R_1 \times \dfrac{R_c}{R_b}} = \frac{\left[R_1 \times \dfrac{R_c}{R_b}\right]_{R_1}}{\left[1 + \dfrac{R_c}{R_a} + \dfrac{R_c}{R_b}\right]_{R_1}}$$

or
$$R_a = \frac{R_1 \times \dfrac{R_c}{R_b}}{\dfrac{(R_aR_b + R_bR_c + R_aR_c)}{R_aR_b}}$$

$$R_1 = \frac{R_aR_b}{R_c}\left[\frac{R_aR_b + R_bR_c + R_aR_c}{R_aR_b}\right] = R_a + R_b + \frac{R_aR_b}{R_c}$$

Similarly, $$R_2 = R_b + R_c + \frac{R_bR_c}{R_a} \text{ and } R_3 = R_a + R_c + \frac{R_aR_c}{R_b}$$

***Q.35. Derive the relation for conversion for star and delta connection.* (R.G.P.V., Dec. 2014)**

Or

***Explain delta/star and star/delta transformations.* (R.G.P.V., Dec. 2016)**

Or

***Write short note on star-delta transformations.* (R.G.P.V., May 2018, 2019)**

Ans. Refer the ans. of Q.33 and Q.34.

NUMERICAL PROBLEMS

Prob.12. Calculate current through 5 ohm resistance using loop analysis.

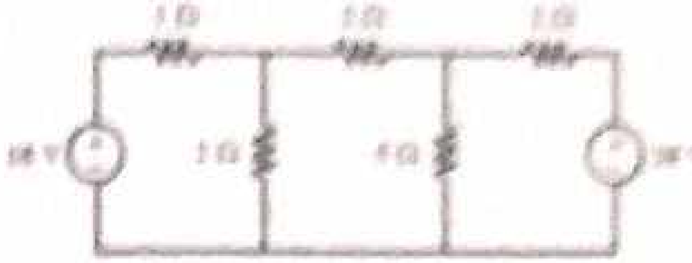


Fig. 1.57 *(R.G.P.V., Dec. 2011)*

Sol. Assign a circulating current to each loop (I_1, I_2 and I_3 as shown in fig. 1.58)

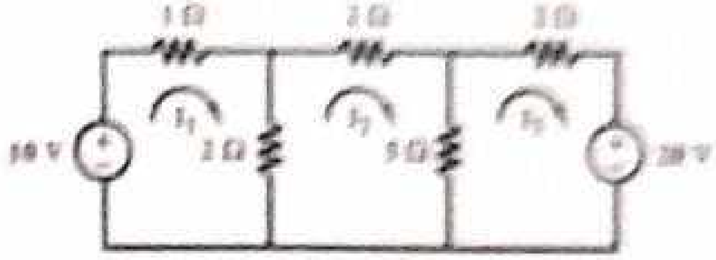


Fig. 1.58

Writing loop equations for the circuit of fig. 1.58.

Loop 1 –

$$-10 + I_1 + 2(I_1 - I_2) = 0$$

$$3I_1 - 2I_2 = 10 \qquad ...(i)$$

Loop 2 –

$$2(I_2 - I_1) + 2I_2 + 5(I_2 - I_3) = 0$$

$$-2I_1 + 9I_2 - 5I_3 = 0 \qquad ...(ii)$$

Loop 3 –

$$5(I_3 - I_2) + 2I_3 = -20$$

$$-5I_2 + 7I_3 = -20 \qquad ...(iii)$$

After solving equations (i), (ii) and (iii), we get

$$I_1 = 2.09 \text{ A}, \; I_2 = -1.86 \text{ A}, \; I_3 = -4.186 \text{ A}$$

Hence, current through 5 Ω resistance

$$= I_2 - I_3 = -1.86 + 4.186 = \mathbf{2.326 \text{ A}} \qquad \textbf{Ans.}$$

Prob.13. Determine the current drawn from the 5 volt battery in the network shown –

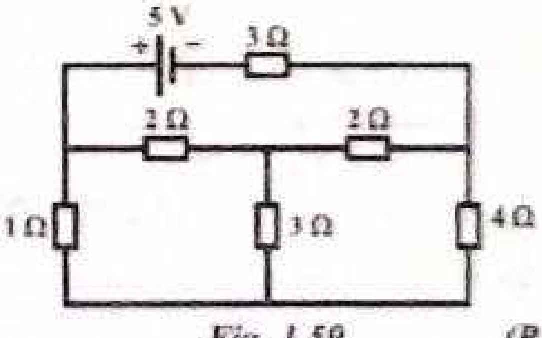


Fig. 1.59 *(R.G.P.V., June 2012)*

Sol. Assign a circulating current to each loop (I_1, I_2 and I_3 as shown in fig. 1.60).

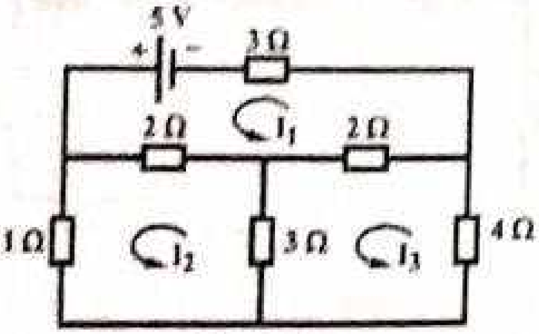


Fig. 1.60

Writing loop equations for the circuits of fig. 1.60.

Loop 1 –

$$5 = 2(I_1 - I_2) + 2(I_1 - I_3) + 3I_1$$

$$7I_1 - 2I_2 - 2I_3 = 5 \qquad \text{...(i)}$$

Loop 2 –

$$0 = 1 \times I_2 + 3(I_2 - I_3) + 2(I_2 - I_1)$$

$$-2I_1 + 6I_2 - 3I_3 = 0 \qquad \text{....(ii)}$$

Loop 3 –

$$0 = 3(I_3 - I_2) + 4I_3 + 2(I_3 - I_1)$$

$$-2I_1 - 3I_2 + 9I_3 = 0 \qquad \text{....(iii)}$$

After solving equations (i), (ii) and (iii), we get

$$I_1 = \frac{75}{77}\text{A}, I_2 = \frac{40}{77}\text{A}, I_3 = \frac{30}{77}\text{A}$$

Hence, the current drawn from the 5 V battery is

$$I_1 = \frac{75}{77}\text{A} \qquad \textbf{Ans.}$$

Prob.14. Determine the current's in all branches of the network shown in fig. 1.61.

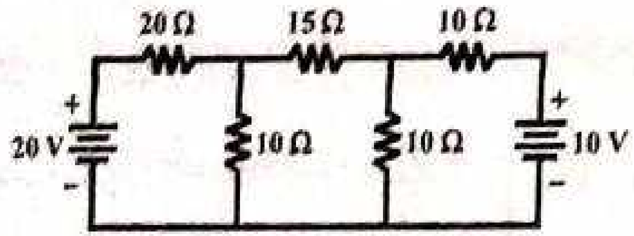


Fig. 1.61

(R.G.P.V., Dec. 2017, May 2018)

Sol. The given figure can be redrawn for nodal analysis as shown in fig. 1.62.

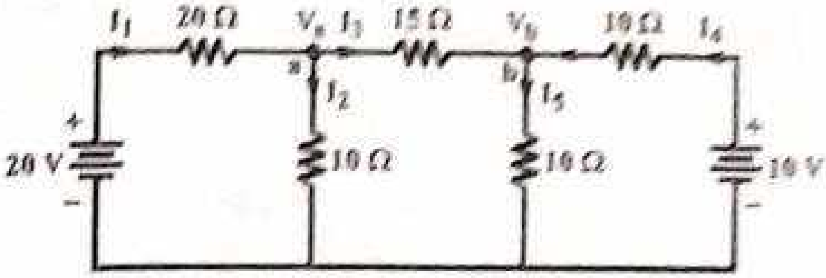


Fig. 1.62

Applying KCL at node a, we obtain

$$\frac{V_a - 20}{20} + \frac{V_a}{10} + \frac{V_a - V_b}{15} = 0$$

$$\frac{3V_a - 60 + 6V_a + 4V_a - 4V_b}{60} = 0 \qquad \text{...(i)}$$

After rearranging equation (i), we get

$$13V_a - 4V_b = 60 \qquad \text{...(ii)}$$

Applying KCL at node b, we obtain

$$\frac{V_b - 10}{10} + \frac{V_b}{10} + \frac{V_b - V_a}{15} = 0$$

$$\frac{3V_b - 30 + 3V_b + 2V_b - 2V_a}{30} = 0 \qquad \text{...(iii)}$$

After rearranging equation (iii), we get

$$-2V_a + 8V_b = 30 \qquad \text{...(iv)}$$

After solving equations (ii) and (iv), we get

$$V_a = 6.25 \text{ V and } V_b = 5.3125 \text{ V}$$

Thus the currents in all branches are given as –

$$I_1 = \frac{20 - V_a}{20} = \frac{20 - 6.25}{20} = \mathbf{0.6875\ Amp.} \qquad \textbf{Ans.}$$

$$I_2 = \frac{V_a}{10} = \frac{6.25}{10} = \mathbf{0.625\ Amp.} \qquad \textbf{Ans.}$$

$$I_3 = \frac{V_a - V_b}{15} = \frac{6.25 - 5.3125}{15} = \mathbf{0.0625\ Amp.} \qquad \textbf{Ans.}$$

$$I_4 = \frac{10 - V_b}{10} = \frac{10 - 5.3125}{10} = \mathbf{0.46875\ Amp.} \qquad \textbf{Ans.}$$

and $$I_5 = \frac{V_b}{10} = \frac{5.3125}{10} = \mathbf{0.53125\ Amp.} \qquad \textbf{Ans.}$$

Prob.15. Find current I using nodal analysis.

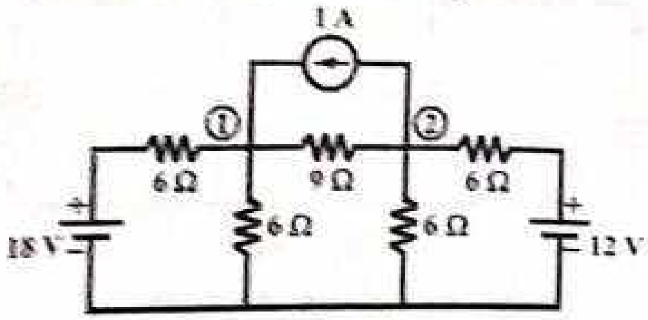


Fig. 1.63

(R.G.P.V., Dec. 2016)

Sol. Consider the voltages at nodes ① and ② be V_1 and V_2. The given circuit is redrawn in fig. 1.64. Nodal equations at nodes ① and ② are as follows –

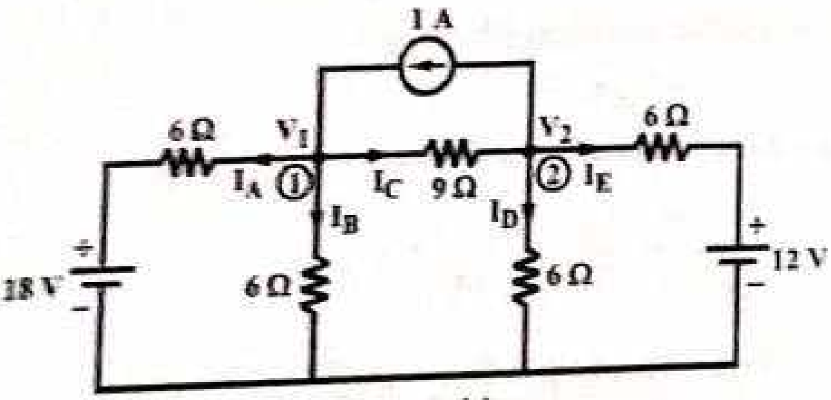


Fig. 1.64

For node ①,

$$\frac{V_1 - 18}{6} + \frac{V_1 - 0}{6} + \frac{V_1 - V_2}{9} - 1 = 0$$

$$\frac{3(V_1 - 18) + 3V_1 + 2(V_1 - V_2)}{18} = 1$$

$$3V_1 - 54 + 3V_1 + 2V_1 - 2V_2 = 18$$

$$8V_1 - 2V_2 = 18 + 54 = 72 \qquad ...(i)$$

For node ②,

$$\frac{V_2 - V_1}{9} + \frac{V_2 - 0}{6} + \frac{V_2 - 12}{6} + 1 = 0$$

$$\frac{2V_2 - 2V_1 + 3V_2 + 3V_2 - 36}{18} = -1$$

$$-2V_1 + 8V_2 = -18 + 36 = 18 \qquad ...(ii)$$

After solving equations (i) and (ii), we obtain

$$V_1 = \frac{51}{5} = 10.2 \text{ V and } V_2 = \frac{24}{5} = 4.8 \text{ V}$$

The current through 6 Ω resistor $= \dfrac{V_1 - 18}{6} = \dfrac{10.2 - 18}{6} = -1.3\text{ A}$ **Ans.**

Current through 9 Ω resistor $= \dfrac{V_1 - V_2}{9} = \dfrac{10.2 - 4.8}{9} = 0.6\text{ A}$ **Ans.**

Current through 6 Ω resistor $= \dfrac{V_1 - 0}{6} = \dfrac{10.2}{6} = 1.7\text{ A}$ **Ans.**

Current through 6 Ω resistor $= \dfrac{V_2 - 0}{6} = \dfrac{4.8 - 0}{6} = 0.8\text{ A}$ **Ans.**

Current through 6 Ω resistor $= \dfrac{V_2 - 12}{6} = \dfrac{4.8 - 12}{6} = -1.2\text{ A}$ **Ans.**

Prob.16. In the circuit of fig. 1.65 find the voltage V_1 across the 6 Ω resistance using nodal method of circuit analysis.

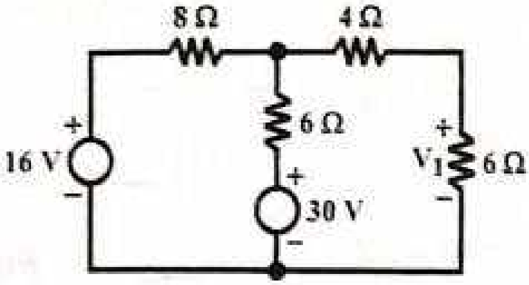


Fig. 1.65 *(R.G.P.V., Dec. 2015)*

Sol. The given circuit is redrawn as shown in fig. 1.66.

Let node voltages of nodes ① and ② be called V and V_1 respectively.

Applying KCL at node ①, we have

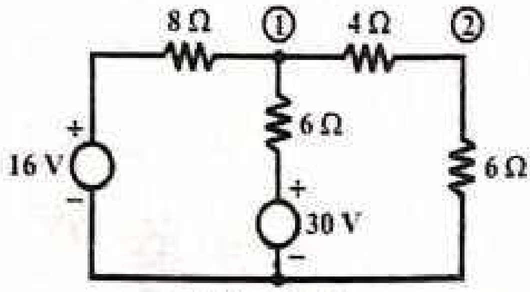


Fig. 1.66

$$\frac{V-16}{8} + \frac{V-30}{6} + \frac{V-V_1}{4} = 0$$

$$\frac{3(V-16) + 4(V-30) + 6(V-V_1)}{24} = 0$$

$$3V - 48 + 4V - 120 + 6V - 6V_1 = 0$$

$$13V - 6V_1 = 168 \qquad ...(i)$$

Now applying KCL at node ②, we have

$$\frac{V_1 - V}{4} + \frac{V_1 - 0}{6} = 0$$

$$6V_1 - 6V + 4V_1 = 0$$

$$-6V + 10V_1 = 0 \qquad ...(ii)$$

After solving equations (i) and (ii), we get

$$V = 17.87\text{ V},\ V_1 = 10.72\text{ V}$$

The voltage across the 6 Ω resistance is **10.72 V** **Ans.**

Prob.17. ***For the circuit shown in fig. 1.67, determine the current I through the 10 Ω resistance by –***

(i) KCL (ii) KVL (iii) Superposition theorem.

(R.G.P.V., Nov. 2018)

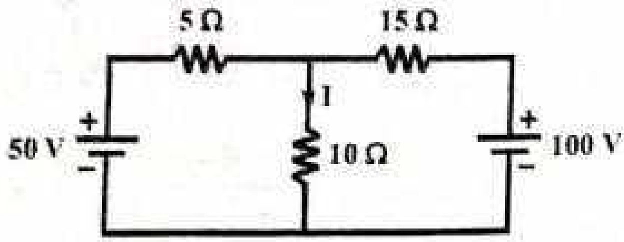


Fig. 1.67

Sol. (i) The given figure can be redrawn as shown in fig. 1.68.

As shown in the figure node (2) has been taken as the reference node. Now find the value of node voltage V_1,

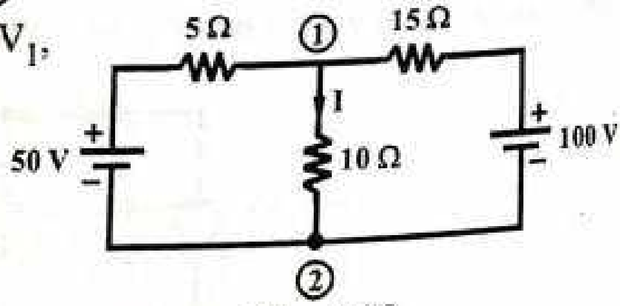


Fig. 1.68

$$V_1\left(\frac{1}{5}+\frac{1}{10}+\frac{1}{15}\right)=\frac{100}{15}+\frac{50}{5}$$

$$0.3667\ V_1 = 16.667$$

or $$V_1=\frac{16.667}{0.3667}=45.45\text{ V}$$

The current I through the 10 Ω resistance is

$$I = \frac{V_1-0}{10}=\frac{45.45}{10}=\mathbf{4.545\ A}$$ **Ans.**

(ii)

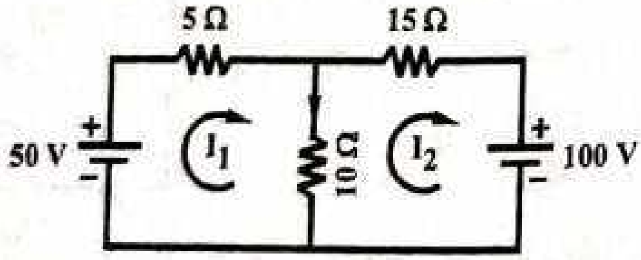


Fig. 1.69

Let us consider mesh currents are I_1 and I_2 in two meshes.

Apply the KVL in mesh 1, we get

$$5I_1 + 10(I_1 - I_2) = 50$$

$$5I_1 + 10I_1 - 10I_2 = 50$$

$$15I_1 - 10I_2 = 50 \quad ...(i)$$

Apply the KVL in mesh 2, we get

$$15I_2 + 10(I_2 - I_1) = -100$$

$$15I_2 + 10I_2 - 10I_1 = -100$$

$$-10I_1 + 25I_2 = -100$$

or $$10I_1 - 25I_2 = 100 \quad ...(ii)$$

After solving equations (i) and (ii), we obtain

$$I_1 = 0.909 \text{ A and } I_2 = -3.636 \text{ A}$$

The current I through the 10 Ω resistance is

$$I = I_1 - I_2 = 0.909 + 3.636 = \mathbf{4.545 \text{ A}}$$ **Ans.**

(iii) The simplified circuit diagram is shown in 1.70.

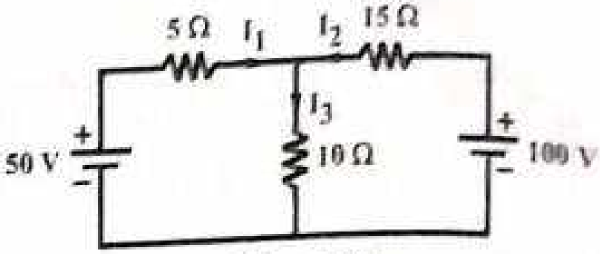


Fig. 1.70

According to superposition theorem, considering the voltage source 50V alone and short circuiting the voltage source 100V, as shown in fig. 1.71 (a).

Total resistance across 50V source is

$$= 5 + \frac{10 \times 15}{10 + 15} = 5 + 6 = 11 \ \Omega$$

Current supplied by the source,

$$I_1' = \frac{50}{11} = 4.545 \text{ A}$$

$$I_2' = 4.545 \times \frac{10}{10+15} = 1.818 \text{ A}$$

$$I_3' = 4.545 \times \frac{15}{25} = 2.727 \text{ A}$$

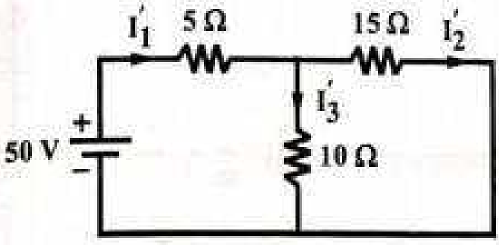


Fig. 1.71 (a)

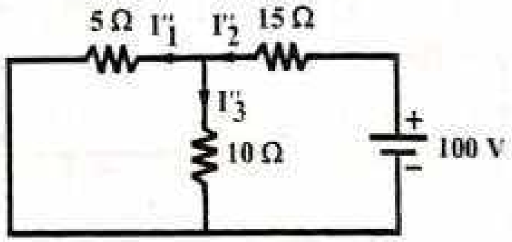


Fig. 1.71 (b)

Now considering the voltage source 100V alone and short circuiting the voltage source 50V, as shown in fig. 1.71 (b).

The total resistance across 100V source is

$$= 15 + \frac{5 \times 10}{5 + 10} = 15 + \frac{10}{3} = 18.33 \ \Omega$$

Current supplied by the source,

$$I_2'' = \frac{100}{18.33} = 5.455 \text{ A}$$

$$I_3'' = 5.455 \times \frac{5}{10+5} = 1.818 \text{ A}$$

The current I through the 10 Ω resistance is

$$I = I_3 = I_3' + I_3'' = 2.727 + 1.818 = \mathbf{4.545 \text{ A}}$$ **Ans.**

Prob.18. ***Determine the value of current in 10 ohm resistor in the network shown ahead using star-delta transformations.***

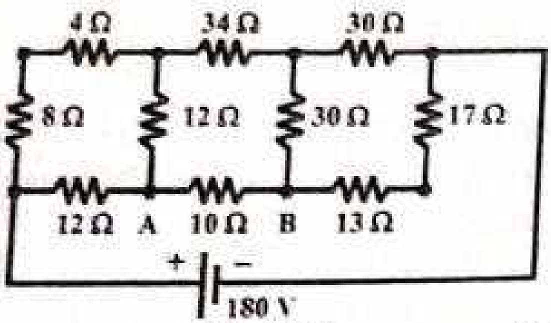


Fig. 1.72 *(R.G.P.V., June 2009)*

Sol. Given circuit can be simplified as shown in fig.1.73.

Equivalent resistance of circuit

$$R_{eq} = (48||24) + 4 + 10$$

$$= \frac{24 \times 48}{24 + 48} + 14 = 16 + 14 = 30\ \Omega$$

Total current drawn from source is

$$I = \frac{V}{R_{eq}} = \frac{180}{30} = 6\ A$$

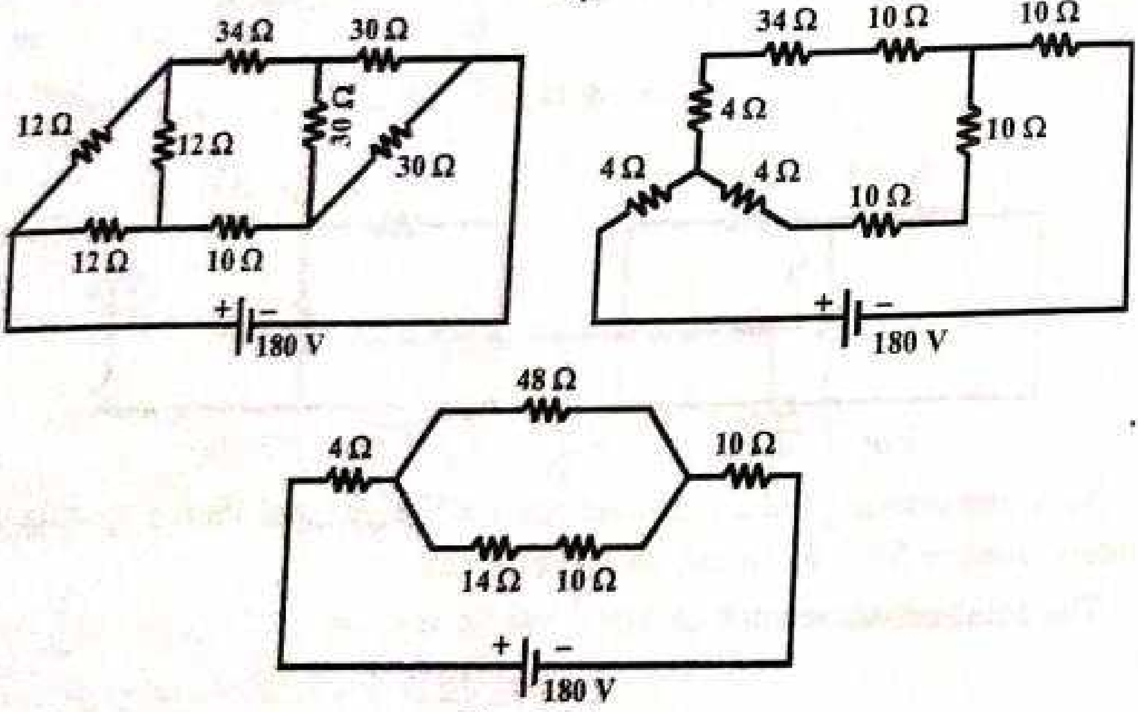


Fig. 1.73

Current flows through 10 Ω resistance can be calculated by using current dividing rule –

$$i = \left(\frac{48}{48 + 14 + 10}\right) \times 6\ A = 4\ A \qquad \textbf{Ans.}$$

UNIT 2

1-PHASE AND 3-PHASE A.C. CIRCUITS

1-PHASE A.C. CIRCUITS – GENERATION OF SINUSOIDAL A.C. VOLTAGE, DEFINITION OF AVERAGE VALUE, R.M.S. VALUE, FORM FACTOR AND PEAK FACTOR OF A.C. QUANTITY

Q.1. Define the following –
(i) A.C. circuit (ii) A.C. voltage.

Ans. (i) A.C. Circuit – The path for the flow of alternating current (A.C.) is known as A.C. circuits. In A.C. circuits, the opposition to the flow of current is due to resistance (R), inductance reactance X_L and capacitance reactance X_C of the circuit. In D.C. circuits, the opposition to the flow of current is only resistance of the circuit. Frequency is very important in A.C. circuits. The currents and voltages are indicated with magnitude (amplitude) and direction (phasors) in these circuits.

(ii) A.C. Voltage – A voltage that changes its polarity and magnitude at regular time intervals is known as A.C. voltage.

Q.2. What is sinusoidal e.m.f. ? How is it generated in a coil ?

Ans. When e.m.f. is plotted against time, a curve similar to the one shown in fig. 2.1 is obtained. This curve is known as ***sine curve*** and the e.m.f. which varies in this manner is known as ***sinusoidal e.m.f.***

An alternating e.m.f. may be generated by rotating a coil in a magnetic field or by rotating a magnetic field within a stationary coil.

Total e.m.f. generated in coil at time t = 2NB*l*v sinωt, where B is the magnetic flux density (in Wb/m^2), *l* is the length of the coil side parallel to the axis (in metres), v is the linear velocity, ω is the angular velocity of the coil, and N is the number of conductors.

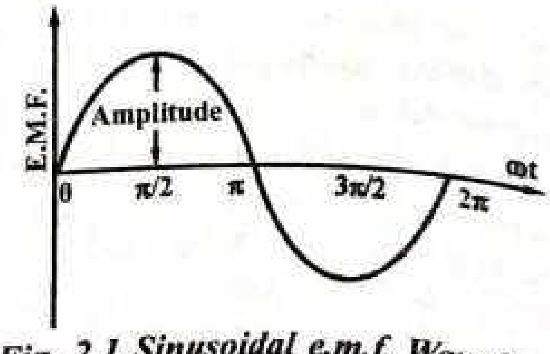


Fig. 2.1 Sinusoidal e.m.f. Waveform

Q.3. Explain the generation of sinusoidal A.C. voltage. Write its equation.

Ans. Let us assume a rectangular coil of N turns placed in a uniform magnetic field as shown in fig. 2.2. The coil moves in the anti-clockwise direction at constant angular velocity of ω (in rad/sec).

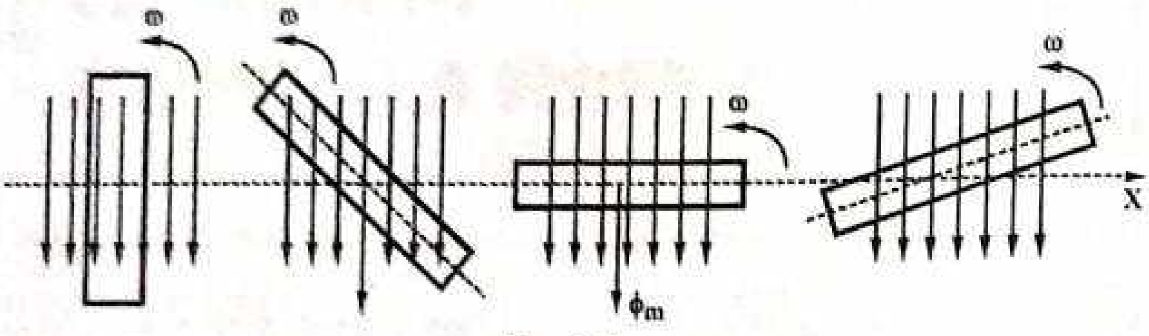


Fig. 2.2

If the coil is in the vertical position, the flux linking the coil is zero since the plane of the coil is parallel to the direction of the magnetic field. Therefore at this position, an e.m.f. induced in the coil is zero. When the coil rotates by some angle in the anti-clockwise direction, there is a rate of change of flux linking the coil and therefore an e.m.f. is induced in the coil according to Faraday's law. The flux linking the coil is maximum when the coil reaches the horizontal position and therefore an e.m.f. induced is also maximum. If the coil further rotates in the anti-clockwise direction, an e.m.f. induced in the coil decreases. Next when the coil comes to the vertical position, an e.m.f. induced becomes zero. After that the same cycle is repeated and an e.m.f. induced in the opposite direction. One cycle of A.C. voltage is generated, when the coil completes one complete revolution.

Equation of Sinusoidal A.C. Voltage – Let us assume a rectangular coil of N turns placed in a uniform magnetic field in the position shown in fig. 2.3. Fig. 2.3 shows the maximum flux linking the coil is in the downward direction. This flux is divided into two components, one component acting along the plane of coil $\phi_m \sin \omega t$ and second component acting perpendicular to the plane of the coil $\phi_m \cos \omega t$.

The component of flux acting along the plane of the coil does not induce any flux in the coil. Only the component acting perpendicular to the plane of the coil i.e. $\phi_m \cos \omega t$ induces an e.m.f. in the coil. According to Faraday's law

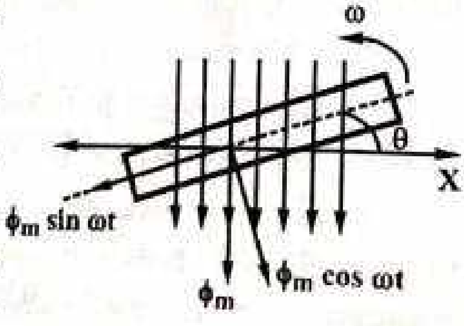


Fig. 2.3

$$e = -N\frac{d\phi}{dt} \qquad [\because \phi = \phi_m \cos \omega t] \quad ...(i)$$

$$= -N\frac{d}{dt}[\phi_m \cos \omega t]$$

$$= -N\phi_m(-\sin \omega t.\omega)$$
$$= N\phi_m \omega \sin \omega t$$
$$= E_m \sin \omega t \qquad [\because E_m = N\phi_m\omega] \quad ...(ii)$$

Thus the e.m.f. induced in the coil is a sinusoidal e.m.f. As a results, a sinusoidal current in the circuit is given by the equation

$$i = I_m \sin \omega t \qquad ...(iii)$$

where, i = Instantaneous value of current in ampere
I_m = Maximum value of current in ampere
ω = Angular velocity in rad/sec.

Q.4. Define the following terms –

(i) Average value ***(R.G.P.V., June 2012, Dec. 2013)***

(ii) R.M.S. value ***(R.G.P.V., June 2012, Dec. 2013)***

(iii) Instantaneous value.

Ans. (i) Average Value – The average value of an alternating current is expressed by that steady current, which transfers equal charge across a given circuit in equal amount of time as transferred by alternating current.

Average value of current or voltage

$$= \frac{2}{\pi} \times (\text{Maximum value of current or voltage})$$
$$= 0.637 \ I_m$$

(ii) R.M.S. (Root Mean Square) Value – The r.m.s. value of an alternating current is defined by that steady (D.C.) current, which when flowing through a given circuit for a given time produces the same heat as produced by the alternating current, when flowing through the same circuit for the same time.

R.M.S. value of alternating current or voltage,

$$= \frac{\text{Maximum value of alternating current or voltage}}{\sqrt{2}}$$
$$= \frac{I_m}{\sqrt{2}}$$
$$= 0.707 \ I_m$$

(iii) Instantaneous Value – The value of an alternating quantity at the time of consideration, which may have any value between zero to maximum depends on position of wave shape and phase angle.

Q.5. What is difference between D.C. and A.C. ? Draw A.C. sine wave and define instantaneous value, average value and R.M.S. value of this A.C. sine wave. ***(R.G.P.V., May 2018)***

Ans. The difference between A.C. and D.C. are as follows –

S.No.	Alternating Current (A.C.)	Direct Current (D.C.)
(i)	Frequency of A.C. is 50 Hz.	Frequency of D.C. is zero.
(ii)	A.C. is more dangerous than D.C. at same voltage ratings.	D.C. is less dangerous at same voltage rating of A.C.
(iii)	Direction of current is not indicated in A.C. symbol. 	Direction of current is indicated in D.C. symbol.  (current flows from –ve to +ve)
(iv)	It varies periodically in magnitude and direction both, in sinusoidal waveform.	It flows in one direction only i.e., no phase change in D.C.
(v)	A.C. transmission is economical.	D.C. transmission is costly.

Also refer the ans. of Q.2 and Q.4.

Q.6. Define the following terms –
(i) Amplitude
(ii) Cycle *(R.G.P.V., June 2007)*
(iii) Time period *(R.G.P.V., June 2007)*
(iv) Frequency. *(R.G.P.V., June 2007)*

Ans. (i) Amplitude – The maximum positive or negative value of an alternating quantity is known as ***amplitude***.

(ii) Cycle – One complete set of positive and negative values of alternating quantity is known as ***cycle***.

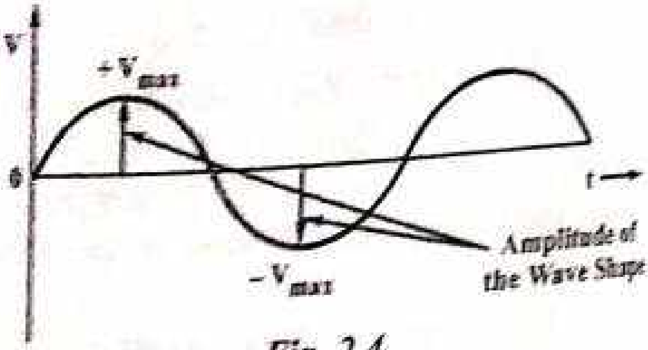


Fig. 2.4

A cycle may also be sometimes specified in terms of angular measure. In that case one complete cycle is said to be spread over 360° or 2π radians.

(iii) Time Period – Time taken to complete one cycle by an alternating quantity is known as its ***time period (T)***, and is equal to inverse of frequency i.e.,

$$T = \frac{1}{f}$$

(iv) Frequency – Number of cycles per second is called the ***frequency***, which is given by

$$f = \frac{PN}{120}$$

where, f = Frequency, P = Number of poles, N = Speed in r.p.m.

Q.7. Explain the following terms pertaining to an A.C. wave –

(i) Time period *(ii) R.M.S. value*

(iii) Average value *(iv) Form factor.*

(R.G.P.V., Dec. 2017)

Ans. ***(i) Time Period*** – Refer the ans. of Q.6 (iii).

(ii) R.M.S. Value – Refer the ans. of Q.4 (ii).

(iii) Average Value – Refer the ans. of Q.4 (i).

(iv) Form Factor – Form factor of alternating wave is defined as the ratio of its r.m.s. value to average value of current over a half cycle.

$$\text{Form factor} = \frac{\text{R.M.S. value of current}}{\text{Average value of current}}$$

For sine wave,

R.M.S. value of current, $I_{r.m.s.} = 0.707\ I_m$

Average value of current, $I_{av} = 0.637\ I_m$

Thus, form factor for sine wave $= \dfrac{0.707\ I_m}{0.637\ I_m} = 1.11.$

Q.8. What do you understand by average value, R.M.S. value, form factor and peak factor in A.C. circuit ? *(R.G.P.V., Nov. 2018)*

Ans. **Average and R.M.S. Values** – Refer the ans. of Q.4 (i) and (ii).

Form Factor – Refer the ans. of Q.7.

Peak Factor – The ratio of maximum value to r.m.s. value of alternating current is known as ***peak factor.***

$$\text{Peak factor} = \frac{\text{Maximum value of current}}{\text{R.M.S. value of current}}$$

Peak factor is also known as ***crest factor*** or ***amplitude factor.***

For a sine wave, peak factor $= \dfrac{I_m}{I_m/\sqrt{2}} = \sqrt{2} = 1.414$

In dielectric insulation testing, knowledge of crest factor is important because the dielectric stress to which the insulation is subjected, is proportional to the maximum or peak value of the applied voltage. When measuring iron losses knowledge of crest factor is also necessary because the iron loss depends on the value of maximum flux.

Q.9. Define the following –

(i) R.M.S. value *(ii) Form factor*

(iii) Peak factor *(iv) Time period*

(v) Frequency.

[R.G.P.V., Nov. 2018(O)]

Ans. (i) R.M.S. *Value* – Refer the ans. of Q.4 (ii).

(ii) ***Form Factor*** – Refer the ans. of Q.7 (iv).

(iii) ***Peak Factor*** – Refer the ans. of Q.8.

(iv) ***Time Period*** – Refer the ans. of Q.6 (iii).

(v) ***Frequency*** – Refer the ans. of Q.6 (iv).

Q.10. What do you mean by phase difference ?

Ans. Consider two sinusoidal waveforms, one voltage and one current,

$$V = V_m \cos(\omega t + \alpha) \quad \text{...(i)}$$

$$I = I_m \cos(\omega t + \beta) \quad \text{...(ii)}$$

where V_m and I_m are maximum or peak values of voltage and current respectively. These waveforms are sketched in fig. 2.5 with the assumption $\beta < \alpha$.

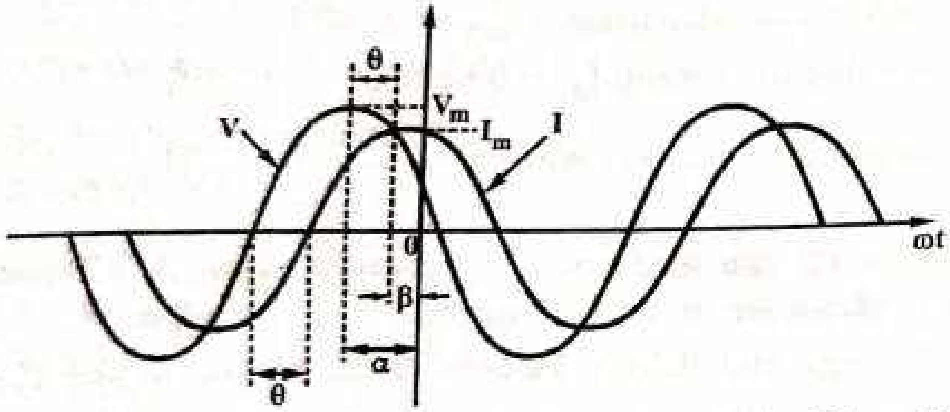


Fig. 2.5 Sinusoidal Current and Voltage Waveforms with a Phase Difference

From this sketch, it is observed that waveform of current is displaced in time (or angle) from that of V, i.e. V and I differ in phase. Positive peaks of I occur later than those of V by an angle θ, θ is called ***phase difference*** and is expressed as

$$\theta = \alpha - \beta$$

Q.11. Discuss the methods to calculate average value and R.M.S. value in an A.C. circuits.

Ans. There are two methods to calculate r.m.s. value and average value–

(i) ***Mid-ordinate Method*** – In this method, we divide the current waveform in several finite intervals as shown in fig. 2.6, and calculate them for a time interval t.

(a) R.M.S. Value – The wave is divided into m equal intervals with average value of instantaneous currents

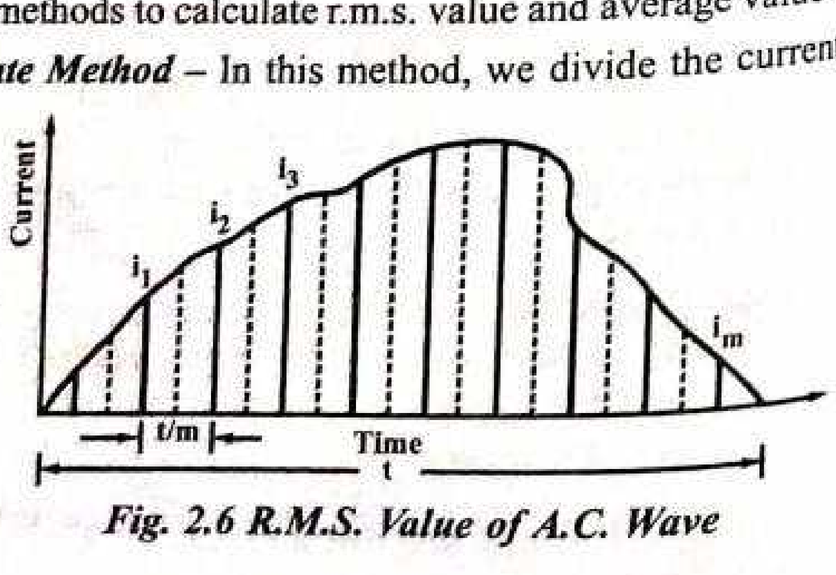


Fig. 2.6 R.M.S. Value of A.C. Wave

during these intervals being $i_1, i_2 ... i_m$. Suppose this wave applied to a circuit consisting of circuit resistance R ohms for m equal intervals of time base t.

Thus, the work done or heat produced by these intervals is as follows –

For 1st interval $= i_1^2 \, Rt/m$ J

,, 2nd ,, $= i_2^2 \, Rt/m$ J

....

....

For m^{th} interval $= i_m^2 \, Rt/m$ J

Let I be the value of direct current, that while flowing through the same resistance R does the same amount of work in same time.

Thus,
$$I^2 Rt = Rt \frac{[i_1^2 + i_2^2 + ... + i_m^2]}{m}$$

$\therefore$
$$I^2 = \frac{i_1^2 + i_2^2 + ... + i_m^2}{m}$$

or
$$I = \sqrt{\frac{i_1^2 + i_2^2 + ... + i_m^2}{m}}$$

= Square root of the mean of the squares of the instantaneous currents.

Similarly, r.m.s. value of alternating voltage is given by the expression

$$V = \sqrt{\frac{v_1^2 + v_2^2 + ... + v_m^2}{m}}$$

(b) Average Value – The average value of sinusoidal and non-sinusoidal wave can be determined by taking arithmatic mean of current or voltage in different intervals.

$$I_{av} = \frac{i_1 + i_2 + i_3 + ... + i_m}{m}$$

(ii) Analytical Method – In this method, we calculate the current waveform for a complete cycle.

(a) R.M.S. Value – Sinusoidal alternating current is given by expression as –

$$i = I_m \sin \theta$$

Mean value of square of the instantaneous values of current over one complete cycle is,

$$= \int_0^{2\pi} \frac{i^2 d\theta}{(2\pi - 0)}$$

The square root of this value is $= \sqrt{\int_0^{2\pi} \frac{i^2 d\theta}{2\pi}}$

Hence, the r.m.s. value of the alternating current is

$$I_{r.m.s.} = \sqrt{\int_0^{2\pi} \frac{I_m^2 \sin^2\theta \, d\theta}{2\pi}}$$

$\because$ $\cos 2\theta = 1 - 2\sin^2\theta$

$$\sin^2\theta = \frac{1-\cos 2\theta}{2}$$

$$\therefore \quad I_{r.m.s.} = \sqrt{\int_0^{2\pi} \frac{I_m^2 (1-\cos 2\theta) d\theta}{2\times 2\pi}} = \sqrt{\frac{I_m^2}{4\pi}\left[\theta - \frac{\sin 2\theta}{2}\right]_0^{2\pi}}$$

$$= \sqrt{\frac{I_m^2 \times 2\pi}{4\pi}} = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}} = 0.707\ I_m$$

i.e., R.M.S. value of current = 0.707 × Maximum value of current

The above expression is also applicable for voltage.

(b) Average Value – Equation for instantaneous value of alternating current is $i = I_m \sin\theta$, then mean value of current over a half cycle given as

$$I_{av} = \int_0^{\pi} \frac{i\, d\theta}{(\pi - 0)} = \frac{I_m}{\pi}\int_0^{\pi} \sin\theta\, d\theta = \frac{I_m}{\pi}[-\cos\theta]_0^{\pi} = -\frac{I_m}{\pi}[-1-1]$$

$$= \frac{2I_m}{\pi} = 0.637\ I_m$$

$\therefore$ Average value of current = 0.637 × Maximum value of current

Same method is applicable for voltage waveforms.

NUMERICAL PROBLEMS

Prob. 1. An alternating current is represented by $i = 70.7 \sin 500\, t$. Determine-(i) frequency (ii) the current 0.0010 second after passing through zero, increasing positively, (iii) R.M.S. and average values of current.

Sol. Given, $i = 70.7 \sin 500\, t$ ...(i)

and $i = I_m \sin \omega t$ ...(ii)

Comparing equations (i) and (ii), we get

(i) $I_m = 70.7$ A,

$\omega = 500$ rad/sec

$2\pi f = 500$

$$f = \frac{500}{2\pi} = \mathbf{79.58\ Hz} \qquad \textbf{Ans.}$$

(ii) $$t = 0.0010 \text{ sec}$$

$$i = 70.7 \sin (500 \times 0.0010)$$

$$= 70.7 \sin (0.5) = \mathbf{0.62\ A} \qquad \textbf{Ans.}$$

(iii) $$I_{r.m.s.} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}} = 49.9 \approx \mathbf{50\ A} \qquad \textbf{Ans.}$$

and $$I_{av} = 0.637\ I_m = 0.637 \times 70.7 = \mathbf{45.03\ A} \qquad \textbf{Ans.}$$

Prob.2. Find the average and R.M.S. values of the following waveforms. Also calculate form factor and peak factor of the same.

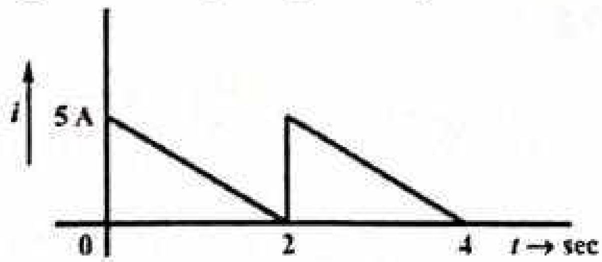


Fig. 2.7 *(R.G.P.V., June 2013)*

Sol. Let time period of wave be T. That is,

$$T = 2 \text{ sec}$$

$$I_{av} = \frac{0+5}{2} = \mathbf{2.5\ A} \qquad \textbf{Ans.}$$

and $$I_{r.m.s.} = \sqrt{\frac{1}{T}\int_0^2 5^2\, dt}$$

$$= \sqrt{\frac{1}{2}\int_0^2 25\, dt} = \sqrt{\frac{25}{2}[t]_0^2}$$

$$= \sqrt{12.5(2-0)} = \sqrt{25} = \mathbf{5\ A} \qquad \textbf{Ans.}$$

$$\text{Form factor} = \frac{I_{r.m.s.}}{I_{av}} = \frac{5}{2.5} = \mathbf{2} \qquad \textbf{Ans.}$$

and $$\text{Peak factor} = \frac{I_m}{I_{r.m.s.}} = \frac{5}{5} = \mathbf{1} \qquad \textbf{Ans.}$$

Prob.3. Calculate the average and effective values of the waveform shown in fig. 2.8. Hence find the form factor.

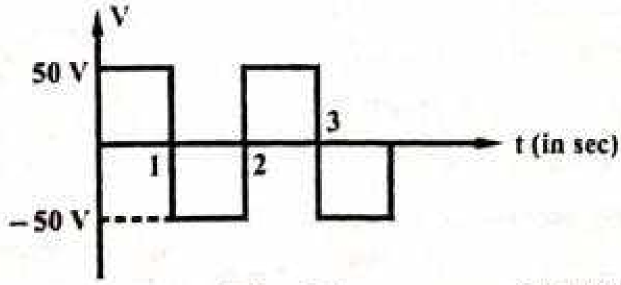


Fig. 2.8 *[R.G.P.V., Nov. 2018(O)]*

Sol. Here, $T = 2$.

Average value is given by

$$V_{av} = \frac{1}{2}\left[\int_0^1 50\,dt + (-50)\int_1^2 dt\right]$$

$$= \frac{1}{2}[50(1-0) - 50(2-1)]$$

$$= \frac{1}{2}[50 - 50] = 0$$ **Ans.**

R.M.S. value is given by

$$V_{eff} = V_{r.m.s.} = \sqrt{\frac{1}{2}\left[\int_0^1 50^2\,dt + \int_1^2 (-50)^2\,dt\right]}$$

$$= \sqrt{\frac{1}{2}[2500(1-0) + 2500(2-1)]}$$

$$= \sqrt{\frac{1}{2} \times 5000} = \sqrt{2500} = 50 \text{ V}$$ **Ans.**

$$\text{Form factor} = \frac{V_{r.m.s.}}{V_{av}} = \frac{50}{0} = \infty$$ **Ans.**

Draw a line OA of length equal to I_m. This line OA rotates in the anti-clockwise direction at a constant angular velocity ω (in rad/sec.) and follows the circular trajectory shown in fig. 2.10. At any instant, the projection of OA on the y-axis is given by OB = OA sin θ = I_m sin ωt. Therefore, the line OA is the phasor representation of the sinusoidal current.

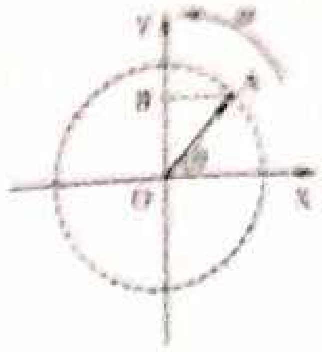


Fig. 2.10 Phase Representation

Q.13. Discuss mathematical representation of phasors.

Ans. The mathematical representation of phasor are of three form –

(i) Rectangular Form – Rectangular method is also called symbolic notation. In this method, the phasor is resolved into horizontal component and vertical component. Phasor can be expressed in the complex form as follows–

$$\overline{V} = x + jy$$

Magnitude of phasor,

$$V = \sqrt{x^2 + y^2}$$

Its angle with OX-axis,

$$\theta = \tan^{-1}(y/x)$$

When angle θ is negative, then

$$\overline{V} = x - jy$$

(ii) Trigonometrical Form – In this method, the horizontal component and vertical component of the phasor can be expressed in the trigonometrical form. For example, horizontal and vertical components are given below –

$$x = V\cos\theta$$

and $$y = V\sin\theta$$

$$\therefore \quad \overline{V} = x + jy = V\cos\theta + jV\sin\theta$$
$$= V(\cos\theta + j\sin\theta)$$

When angle θ is negative, then

$$\overline{V} = V(\cos\theta - j\sin\theta)$$

(iii) Polar Form – A polar form is a short form of trigonometrical representation of a phasor. It is given by

$$\overline{V} = V\angle\theta$$

When angle θ is negative, then

$$\overline{V} = V\angle -\theta$$

Hence, one form is converted into the other form rapidly as per the requirement to speed up the calculations.

Q.14. Explain the concept of phasor and vector.

Ans. Vector is a multidimensional quantity it contains both magnitude and direction. Phasor is a two dimensional vector and it is used in electrical technology that relates to voltage and current. The sinusoidal currents and voltages can be represented by phasors. A phasor is a vector rotating at a constant angular velocity. In this case, the constant angular velocity is ω and it is also known as the frequency of sinusoid. Consider a voltage wave in the form –

$$v = V_m \cos(\omega t + \theta) \quad ...(i)$$

$$v = \sqrt{2} V \cos(\omega t + \theta) \quad ...(ii)$$

where, V_m is peak (maximum) value and V is root mean square (r.m.s.) value of the voltage. The voltage, V can be represented as the real part of a complex function that is we can write the expression in the form –

$$V = \mathrm{Re}\left[V_m e^{(j\omega t + \theta)}\right] \quad ...(iii)$$

$$V = \mathrm{Re}\left[\left(V e^{j\theta}\right)\left(\sqrt{2}\, e^{j\omega t}\right)\right] \quad ...(iv)$$

The complex function in equation (iv) broken up into two parts such as in first part $V e^{j\theta}$ is a complex constant and the second part $\sqrt{2}\, e^{j\omega t}$ implies rotation at angular velocity, ω. This second part is the same for all sinusoid voltages and currents in a particular problem and need not be written. This is not required because all voltages and currents in a particular problem are to the same frequency. The phasor V_m is rotating at angular velocity ω and its horizontal projection is $V_m \cos(\omega t + \theta)$. It is observed that the vertical projection of the phasor is $V_m \sin(\omega t + \theta + \pi/2)$ which is equal to horizontal projection of $V_m \cos(\omega t + \theta)$ at all instants of time that is $a_1 = a_2$. Note that the cosine variation is the projection of a radial line of length V_m on the X-axis as seen in fig. 2.11.

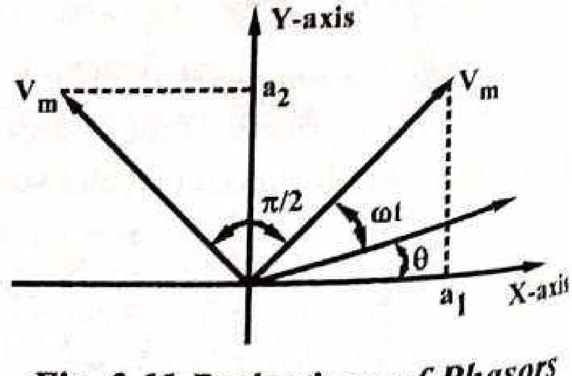


Fig. 2.11 Projections of Phasors $V_m e^{(j\omega t + \theta)}$ on X-axis and $V_m e^{(j\omega t + \theta + \pi/2)}$ on Y-axis

Therefore, we can write the function as a sinewave or a cosinewave only the difference being the phase difference of $\pi/2$. For a sinusoid the effective value is the most important value it is used in all phasor diagram. The angle between two positions of phasor is the phase difference between the corresponding points on the cosine function. If a voltage or current is expressed as a sine and it will be changed to a cosine by subtracting $90°$ from the phase.

Q.15. Write down the addition, subtraction, multiplication and division of phasor quantities.

Ans. **Addition** – For addition and subtraction, the rectangular form is the best suited. Hence, if the phasor quantities are given in polar form, they are first converted into rectangular form and then added or subtracted. Let us assume two voltage phasors are given below –

$$\overline{V}_1 = x_1 + j\, y_1 \qquad \text{...(i)}$$

and

$$\overline{V}_2 = x_2 - j\, y_2 \qquad \text{...(ii)}$$

For this case, horizontal components and vertical components are added separately as given below –

$$\overline{V} = \overline{V}_1 + \overline{V}_2$$
$$= x_1 + j\, y_1 + x_2 - j\, y_2$$
$$= (x_1 + x_2) + j\,(y_1 - y_2)$$

Resultant magnitude is,

$$V = \sqrt{(x_1 + x_2)^2 + (y_1 - y_2)^2}$$

and angle θ is,

$$\theta = \tan^{-1}\left[\frac{(y_1 - y_2)}{(x_1 + x_2)}\right]$$

Subtraction – Subtraction is similar to addition. Let us consider phasor $\overline{V}_2$ is subtracted from phasor $\overline{V}_1$.

$$\overline{V} = \overline{V}_1 - \overline{V}_2$$
$$= x_1 + j\, y_1 - x_2 + j\, y_2 = (x_1 - x_2) + j\,(y_1 + y_2)$$

Resultant magnitude is,

$$V = \sqrt{(x_1 - x_2)^2 + (y_1 + y_2)^2}$$

and angle θ is,

$$\theta = \tan^{-1}\left[\frac{(y_1 + y_2)}{(x_1 - x_2)}\right]$$

Multiplication – For multiplication and division, the polar form is the best suited. Therefore, if the phasor quantities are given in rectangular form, they are first converted into polar form. Let us assume two voltage phasors are given below –

$$\overline{V}_1 = x_1 + j\, y_1 = V_1 \angle\theta_1 \qquad \text{...(iii)}$$

and

$$\overline{V}_2 = x_2 - j\, y_2 = V_2 \angle -\theta_2 \qquad \text{...(iv)}$$

From equations (iii) and (iv), multiply their magnitudes and add their angles,

$$\overline{V}_1 \times \overline{V}_2 = V_1\angle\theta_1 \times V_2 \angle -\theta_2 = V_1 V_2 \angle(\theta_1 - \theta_2)$$

Division – From equations (iii) and (iv), divide their magnitudes and subtract their angles.

$$\frac{\overline{V}_1}{\overline{V}_2} = \frac{V_1\angle\theta_1}{V_2\angle-\theta_2} = \frac{V_1}{V_2}\angle\theta_1-(-\theta_2) = \frac{V_1}{V_2}\angle(\theta_1+\theta_2)$$

***Q.16. Define the power factor.* (R.G.P.V., June 2011, Dec. 2012, 2013)**

Or

Define and explain power factor. **(R.G.P.V., June 2017)**

Ans. Power factor is the cosine of the angle between the applied voltage and resultant current flowing through the circuit, where waveform of voltage and current follow sine wave shape.

Power factor of the circuit can be calculated as –

(i) Cosine of the angle of lead or lag.

(ii) From ratio of resistance and impedance.

(iii) From ratio of active power and apparent power.

"The power factor for an inductive circuit is always lagging whereas it is always leading for a capacitive circuit".

Q.17. Explain the meaning and significance of the power factor of a circuit. **(R.G.P.V., Dec. 2015)**

Ans. **Meaning** – Refer the ans. of Q.16.

Significance of the Power Factor – The power factor of an A.C. circuit plays an important role in the power system. Hence power of an A.C. circuit can be expressed as –

$$P = VI\cos\phi$$

or

$$I = \frac{P}{V\cos\phi} \quad \text{...(i)}$$

From equation (i), it should be noted that for a fixed power at constant voltage, the current represented by the circuit rises with reduce in power factor. Therefore, at low power factor, A.C. circuits draw much more current from their mains. The main disadvantages of low power factor are –

(i) Poor Efficiency – The conductors have to carry higher current that increases copper losses at low power factors. As a result, efficiency is poor.

(ii) Higher Conductor Size – Conductors are to carry large current for same power at low power factors. Thus they need higher cross-section area.

(iii) Larger kVA Rating of Equipment – At lower pf, the kVA rating of equipment and electrical machines connected in the power system like

transformers, alternators and switch gears will be higher. Because kVA rating is inversely proportional to cos ϕ(i.e., kVA = kW/cos ϕ).

(iv) Larger Voltage Drop – The conductors have to carry higher current that increases voltage drop at low pf as a result, the voltage regulation is poor.

Q.18. What do you mean by Q-factor of a coil ?

Ans. Reciprocal of power factor is called the ***Q-factor*** of a coil or its figure of merit. It is also known as ***quality factor*** of a coil.

$$\text{Q-factor} = \frac{1}{\text{Power factor}} = \frac{1}{\cos\phi} = \frac{1}{R/Z} = \frac{Z}{R}$$

Also, $$Q = 2\pi.\frac{\text{Maximum energy stored in the coil}}{\text{Energy dissipated per cycle}}$$

Q.19. Define and draw power triangle.

Ans. **Power Triangle for Leading Power Factor** – In case of leading power factor, circuit have capacitive nature. Triangle for leading power factor shown in fig. 2.12. Where P, Q, S are active, reactive, apparent powers and ϕ is the angle by which current leads to applied voltage.

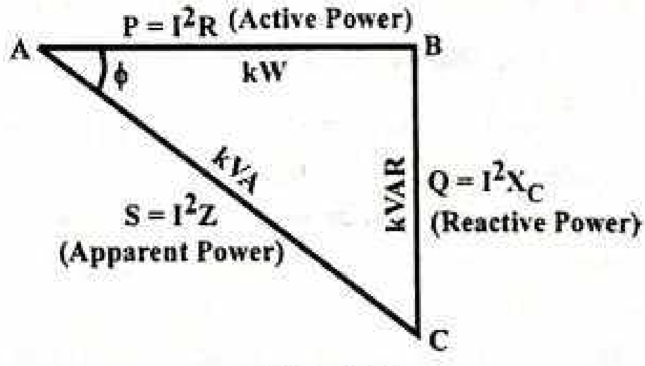
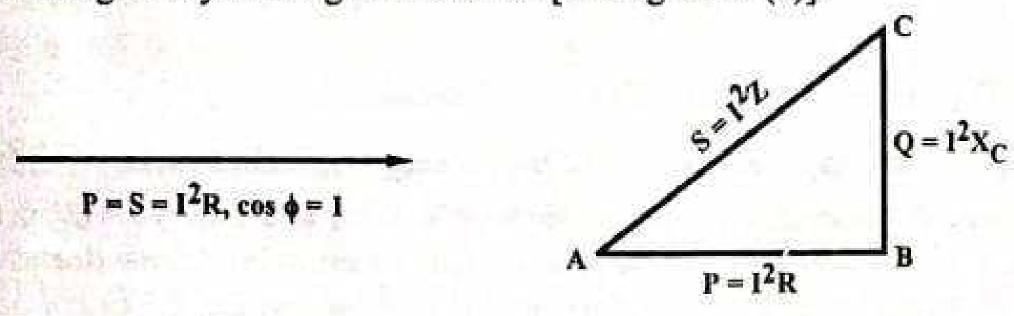


Fig. 2.12

Power Triangle for Unity Power Factor – In case of unity power factor, reactive component remains zero and power factor angle i.e., $\phi = 0°$.

Thus, apparent power will be equal to active power and in diagram of power triangle only a straight line exists [see fig. 2.13 (a)].



(a) *(b)*

Fig. 2.13

Power Triangle for Lagging Power Factor – In case of lagging power factor, circuit have inductive reactance and current lags behind voltage by angle φ.

Power triangle for lagging power factor is shown in fig. 2.13 (b), where P, Q, S are the apparent power, active power and reactive power.

Q.20. Define the following terms –

(i) Resistance (ii) Reactance (iii) Impedance and admittance.

Ans. (i) Resistance – Resistance is defined as the property of a material due to which it opposes the flow of electric current. The unit of resistance (R) being 'Ω' (ohm).

It depends on dimension and resistivity of conductor as given below

$$R = \rho \frac{l}{A}$$

where, R = Resistance in ohm (Ω)

ρ = Resistivity of conductor (Ω-m)

l = Length of conductor in metre (m)

A = Area of cross-section of conductor in metre^2 (m^2).

(ii) Reactance – Reactance is defined as the property of a circuit by which simultaneous change in current and voltage opposes in that circuit.

The unit of reactance is Ω (ohm), and reactance is denoted as X. This is of two types –

(a) Capacitive reactance (X_C) (b) Inductive reactance (X_L).

(iii) Impedance – Impedance in an A.C. circuit is defined as the ratio of the voltage applied to the circuit to the resultant current flowing in the circuit. It is denoted by the symbol Z and expressed in Ω. This is a complex quantity, in which resistance is real part and reactance exists as imaginary part.

$$Z = R + jX$$

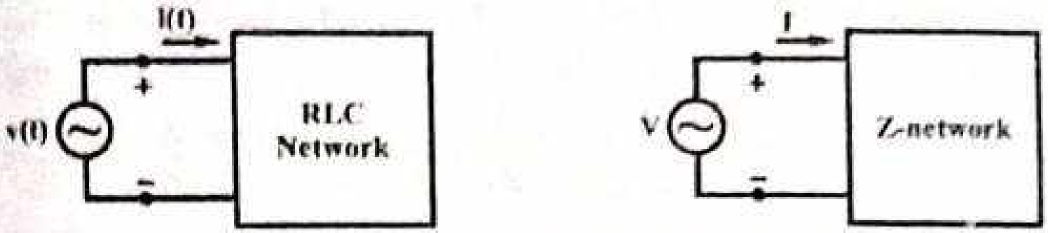
Admittance – The admittance of an A.C. circuit is defined as the reciprocal of its impedance. It is denoted by the symbol Y.

i.e., $$Y = \frac{1}{Z}$$

The unit of admittance (Y) is '℧' (mho).

Q.21. Discuss the concept of impedance and admittance.

Ans. A sinusoidal voltage or current applied to a passive RLC network produces a sinusoidal response. The circuit is said to be in time domain with time functions such as v(t) and i(t) and it is shown in fig. 2.14 (a) when the circuit is analyzed using phasors then it is said to be in the frequency domain shown in fig. 2.14 (b).



(a) Time Domain Network *(b) Frequency Domain Network*

Fig. 2.14

The equations for voltage and current may be written in the form

$$v(t) = V\cos(\omega t + \theta) \quad \text{...(i)}$$

$$v(t) = \text{Re}\left[Ve^{j\omega t}\right] \quad \text{...(ii)}$$

where, $v = V\angle\theta$

$$i(t) = I\cos(\omega t + \phi) \quad \text{...(iii)}$$

$$i(t) = \text{Re}[Ie^{j\omega t}] \quad \text{...(iv)}$$

where, $I = I \angle \phi$

The ratio of phasor voltage, V to phasor current, I is defined by the impedance, Z in the form

$$Z = V/I \quad \text{...(v)}$$

The reciprocal of the impedance, Z is called admittance, Y so that we write as

$$Y = 1/Z \quad \text{...(vi)}$$

The impedance Z and the admittance Y are complex numbers when impedance is written in Cartesian form the real part is the resistance, R and the imaginary part is the reactance, X. The value of X is positive then it is called ***inductive reactance*** and when value of X is negative it is called ***capacitive reactance.*** When the admittance written in Cartesian form the real part is conductance, G and the imaginary part is susceptance, B. A positive sign on the susceptance indicates a capacitive susceptance and a negative sign indicates an inductive susceptance. Therefore, these are expressed by equations as –

$$Z = R + jX_L, \; Z = R - jX_C \quad \text{...(vii)}$$

$$Y = G - jB_L, \; Y = G + jB_C \quad \text{...(viii)}$$

The relationship between these terms are obtained from the relation Z = 1/Y as follows –

$$R = \frac{G}{G^2 + B^2}, \quad X = \frac{-B}{G^2 + B^2} \quad \text{...(ix)}$$

$$G = \frac{R}{R^2 + X^2}, \; B = \frac{-X}{R^2 + X^2} \quad \text{...(x)}$$

The combination of impedances exactly like resistances. Because the relation in the frequency domain V = IZ is formally identical to relation in the time domain V = IR (Ohm's law). The combination of impedances in series

and parallel forms are expressed as –

Impedance in series – $(Z_{eq}) = Z_1 + Z_2 + ...$ ...(x

Impedance in parallel – $\left(\frac{1}{Z_{eq}}\right) = \frac{1}{Z_1} + \frac{1}{Z_2} + ...$ ...(x

Particularly the combination of two impedances in parallel form are

$$Z_{eq} = \frac{Z_1 Z_2}{Z_1 + Z_2} \qquad ...(xii)$$

In the impedance diagram, an impedance Z is represented by a point in the right half of the complex plane. The fig. 2.15 shows two impedances such as Z_1 in the first quadrant that exhibits inductive reactance while Z_2 in the fourth quadrant exhibits capacitive reactance. By the vector addition their series equivalent is obtained as $Z_1 + Z_2$. We note that vectors are shown without arrowheads in order to distinguish these complex numbers from the phasors.

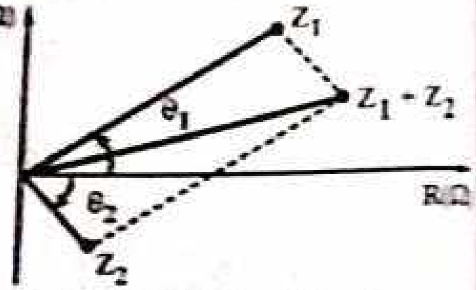


Fig. 2.15 Graphical Representation of the Impedances

The combination of admittances are obtained by just replacing Z by 1/Y in the equations (xi) and (xii) then we obtain as

Admittance in series $\left(\frac{1}{Y_{eq}}\right) = \frac{1}{Y_1} + \frac{1}{Y_2} + ...$ ...(xiv

Admittance in parallel $(Y_{eq}) = Y_1 + Y_2 + ...$ ...(xv

Therefore, we can say that the series circuit are easiest treated in terms of impedance and the parallel circuits in terms admittance. The admittance diagram is analogous to the impedance diagram. The admittance diagram is shown in fig. 2.16 with admittance Y_1 having capacitive susceptance and the admittance Y_2 having inductive susceptance together with their vector sum $Y_1 + Y_2$ which is the parallel combination of the admittances Y_1 and Y_2.

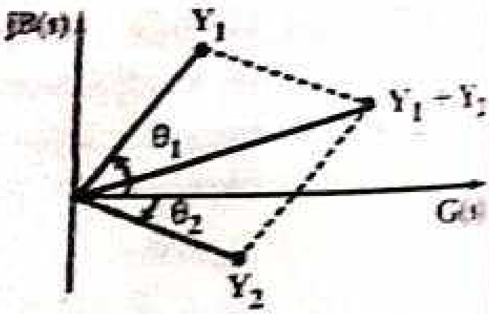


Fig. 2.16 Graphical Representation of the Admittances

Q.22. Explain what is impedance ? What role does it play in phasor diagrams ? ***(R.G.P.V., Dec. 2015)***

Ans. Refer the ans. of Q.20 (iii) and Q.21.

Q.23. Write short note on admittance. ***(R.G.P.V., May 2019)***

Ans. Refer the ans. of Q.20 (iii) and Q.21.

Q.24. Explain in brief the following –

(i) Active (real) power (ii) Reactive power.

(R.G.P.V., June 2011, 2012, Dec. 2013, 2014)

(iii) Apparent power (R.G.P.V., June 2011, Dec. 2012, 2013, 2014)

Or

Explain in brief the active and reactive power. (R.G.P.V., Dec. 2012)

Or

Define and explain active, reactive and apparent power. (R.G.P.V., June 2017)

Or

What is active, reactive and apparent power in RLC series circuit ?

(R.G.P.V., Nov. 2018)

Or

Write an introductory note on active, reactive and apparent power.

(R.G.P.V., May 2019)

Ans. (i) Active (real) Power – Power dissipated in the resistance of a circuit is known as ***real or active or average power.***

$$\text{Active power, } P = V_{r.m.s.}\, I_{r.m.s.} \cos\phi = \frac{1}{2} V_m I_m \cos\phi \text{ (watts)}$$

where, $\cos\phi$ is the power factor of the circuit.

(ii) Reactive Power – Power dissipated in the reactive component of the circuit is known as ***reactive power.***

$$\text{Reactive power, } Q = V_{r.m.s.}\, I_{r.m.s.} \sin\phi \text{ (VAR)}$$

(iii) Apparent Power – The product of r.m.s. value of applied voltage and circuit current is known as the apparent power, which is generally greater than active power.

$$\text{Apparent power, } S = V_{r.m.s.}\, I_{r.m.s.} \text{ (VA)}$$

Q.25. Define the following terms –

(i) Active power (ii) Reactive power (iii) Apparent power

(iv) Power factor (v) Alternation (vi) Frequency.

(R.G.P.V., June 2016)

Ans. (i) Active Power – Refer the ans. of Q.24 (i).

(ii) Reactive Power – Refer the ans. of Q.24 (ii).

(iii) Apparent Power – Refer the ans. of Q.24 (iii).

(iv) Power Factor – Refer the ans. of Q.16.

(v) Alternation – One half cycle is known as alternation. An alternation spans 180 electrical degrees.

(vi) Frequency – Refer the ans. of Q.6 (iv).

Q.26. Prove that average power in A.C. circuit is equal to VIcos ϕ where ϕ is power factor lagging angle. (R.G.P.V., Jan./Feb. 2006)

Ans. Instantaneous power drawn by an A.C. circuit is equal to the product of instantaneous values of voltage and current.

Thus, instantaneous power = $v \times i$ ...(i)

Let the instantaneous value of applied voltage to a circuit be given by,

$$v = V_m \sin \omega t \quad ...(ii)$$

For a general case, the current flowing in the A.C. circuit is assumed to lag the applied voltage by an angle ϕ.

Then the instantaneous value of current is given by,

$$i = I_m \sin (\omega t - \phi) \quad ...(iii)$$

Replacing equations (ii) and (iii) into equation (i), we get

$$\text{Instantaneous power} = V_m \sin \omega t \times I_m \sin (\omega t - \phi)$$

$$= \frac{1}{2} V_m I_m \{\cos \phi - \cos (2\omega t - \phi)\}$$

$$= \frac{1}{2} V_m I_m \cos \phi - \frac{1}{2} V_m I_m \cos (2\omega t - \phi) \quad ...(iv)$$

Above equation (iv) consists of two components –

(i) $\frac{1}{2} V_m I_m \cos \phi$, which remains constant irrespective of time,

and (ii) $\frac{1}{2} V_m I_m \cos (2\omega t - \phi)$, indicating the variation of this component of power at twice the supply frequency.

Since the average value of this component over one complete cycle is zero and hence it does not contribute towards the average value of power drawn from the supply.

Therefore, average power over one complete cycle is given by,

$$P = \frac{1}{2} V_m I_m \cos \phi = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos \phi \quad \left[\because \frac{V_m}{\sqrt{2}} = V\right]$$

$$P = VI \cos \phi \quad ...(v)$$

In the above expression, V and I are the r.m.s. values of applied voltage and current flowing in the circuit and $\cos \phi$ commonly termed as power factor.

ANALYSIS OF R-L, R-C, R-L-C SERIES & PARALLEL CIRCUIT

Q.27. With the help of waveform, comment on phase relation between voltage, current and power in a pure resistive circuit.

Ans. The circuit containing a pure resistance of R ohms is shown in fig 2.17.

Let the alternating voltage applied across the circuit be given by the equation –

$$v = V_m \sin \omega t \qquad ...(i)$$

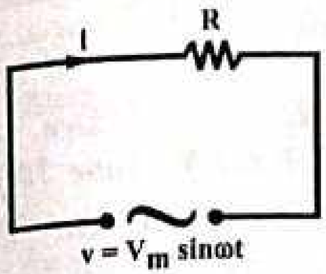
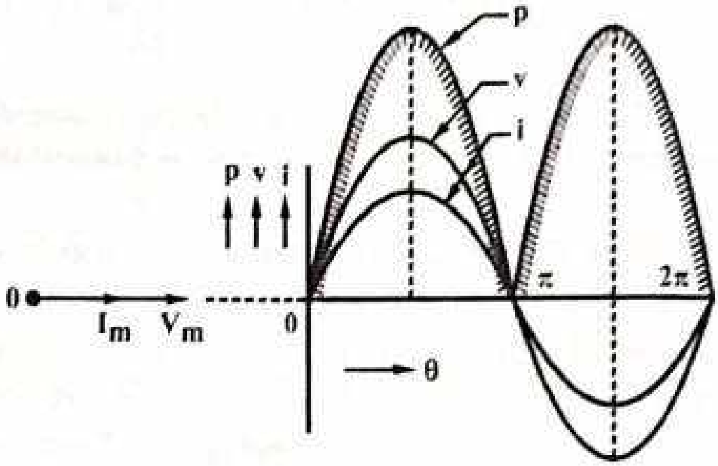


Fig. 2.17



(a) *(b)*

Fig. 2.18

Then the instantaneous value of current flowing through the resistor will be

$$i = \frac{v}{R} = \frac{V_m \sin \omega t}{R} \qquad ...(ii)$$

The value of current will be maximum when $\omega t = 90^\circ$ or $\sin \omega t = 1$

$\therefore$ Maximum current

$$I_m = \frac{V_m}{R}$$

Substituting this value in equation (ii), we get

$$i = I_m \sin \omega t \qquad ...(iii)$$

Instantaneous power,

$$p = vi$$

$$= (V_m \sin \omega t)(I_m \sin \omega t)$$

$$= \frac{V_m I_m}{2} 2 \sin^2 \omega t = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} (1 - \cos 2\omega t)$$

$$p = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} - \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos 2\omega t$$

Average power consumed in the circuit over a complete cycle,

$$P = \text{Average of} \left(\frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \right) - \text{Average of} \left(\frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos 2\omega t \right)$$

$$P = V_{r.m.s.} I_{r.m.s.} - 0$$

or $$P = VI$$

From equations (i) and (iii), it is clear that there is no phase difference between applied voltage and current flowing through pure resistive circuit i.e.,

phase angle between voltage and current is zero. The phasor diagram and waveform are shown in figs. 2.18 (a) and (b) respectively.

Hence, in an A.C. circuit containing pure resistance, current is in phase with the voltage.

Q.28. With the help of waveform, comment on phase relation between voltage, current and power in a pure inductive circuit.

Or

Show that the power consumed by a pure inductive circuit is zero.

(R.G.P.V., June 2016)

Ans. Fig. 2.19 shows a circuit having a pure inductance of L henry. Let the alternating voltage applied across the circuit be given by

$$v = V_m \sin \omega t \qquad ...(i)$$

Due to which, an alternating current i flows through the inductance which induces an e.m.f. in it, given by the relation,

$$e = -L\frac{di}{dt}$$

This induced e.m.f. is equal and opposite to the applied voltage,

$$v = -e = -\left(-L\frac{di}{dt}\right)$$

or $$V_m \sin \omega t = L\frac{di}{dt} \text{ or } di = \frac{V_m}{L} \sin \omega t \, dt$$

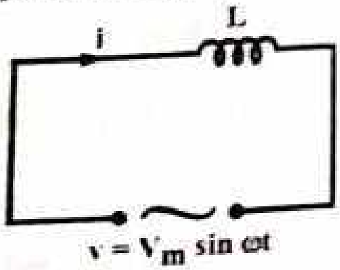


Fig. 2.19

Integrating both sides,

$$\int di = \int \frac{V_m}{L} \sin \omega t \, dt$$

$$i = \frac{-V_m}{\omega L} \cos \omega t = \frac{V_m}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right) \qquad ...(ii)$$

where $\omega L = X_L$ is the opposition offered to the flow of alternating current by a pure inductance and is called inductive reactance. The value of current will be maximum when

$$\sin\left(\omega t - \frac{\pi}{2}\right) = 1$$

$$\therefore \qquad I_m = \frac{V_m}{\omega L}$$

Substituting this value in equation (ii), we have

$$i = I_m \sin\left(\omega t - \frac{\pi}{2}\right) \qquad ...(iii)$$

From equations (i) and (iii), it is clear that current flowing through a pure inductive circuit lags behind the applied voltage by 90°. The phasor diagram and waveform is shown in figs. 2.20 (a) and (b) respectively.

Instantaneous power,

$$p = vi$$

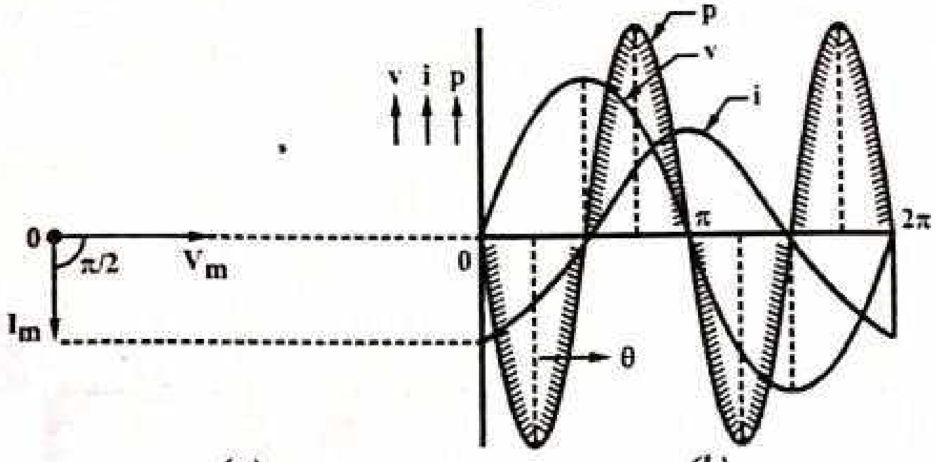
$$= V_m \sin \omega t \times I_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$= \frac{V_m I_m}{2} 2 \sin \omega t \cos \omega t = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \sin 2\omega t$$

Average power consumed in the circuit over a complete cycle,

$$P = \text{Average of } \frac{V_m}{\sqrt{2}} . \frac{I_m}{\sqrt{2}} \sin 2\omega t = 0$$

Hence, average power consumed in a pure inductive circuit is zero. The power curve for this circuit is shown in fig. 2.20 (b).



(a) *(b)*

Fig. 2.20

Q.29. With the help of waveform, comment on phase relation between voltage, current and power in a pure capacitive circuit.

Ans. The circuit containing a pure capacitor of capacitance C farads is shown in fig. 2.21. Let the alternating voltage applied across the circuit be given by

$$v = V_m \sin \omega t \quad ...(i)$$

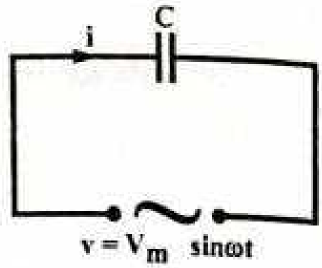


Fig. 2.21

Charge on the capacitor at any instant,

$$q = Cv$$

Current flowing through the circuit,

$$i = \frac{dq}{dt} = \frac{d}{dt}(Cv) = \frac{d}{dt}(C\, V_m \sin \omega t)$$

$$i = \omega C V_m \cos \omega t = \frac{V_m}{1/\omega C} \sin\left(\omega t + \frac{\pi}{2}\right) \quad ...(ii)$$

$$= \frac{V_m}{X_c} \sin\left(\omega t + \frac{\pi}{2}\right)$$

where $\frac{1}{\omega C} = X_C$ is the opposition offered to the flow of alternating curr by a pure capacitor and is called capacitive reactance.

The value of current will be maximum when

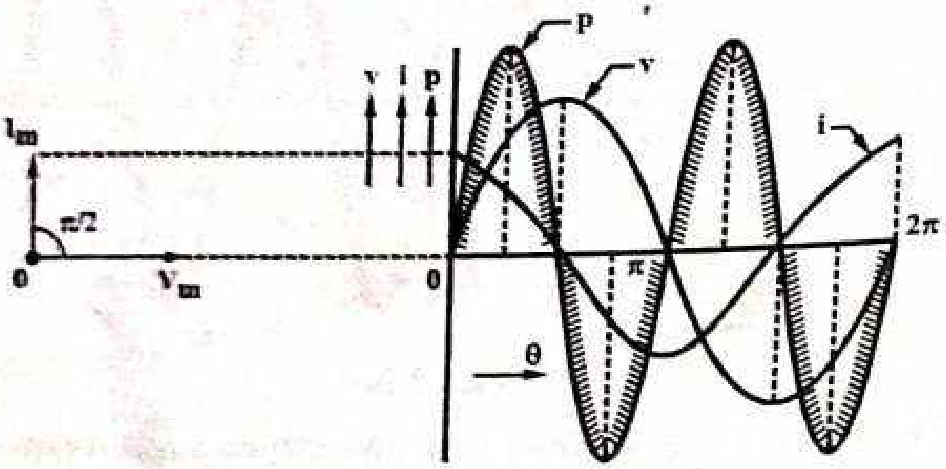
$$\sin\left(\omega t + \frac{\pi}{2}\right) = 1$$

$$\therefore \qquad I_m = \frac{V_m}{1/\omega C} = \frac{V_m}{X_C}$$

Substituting this value in equation (ii), we have

$$i = I_m \sin\left(\omega t + \frac{\pi}{2}\right) \qquad ...(iii)$$

From equations (i) and (iii), it is clear that current flowing through pur capacitive circuit leads the applied voltage by 90°. The phasor diagram an waveform are shown in figs. 2.22 (a) and (b) respectively.



(a) *(b)*

Fig. 2.22

Instantaneous power,

$$p = vi = V_m \sin\omega t \times I_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

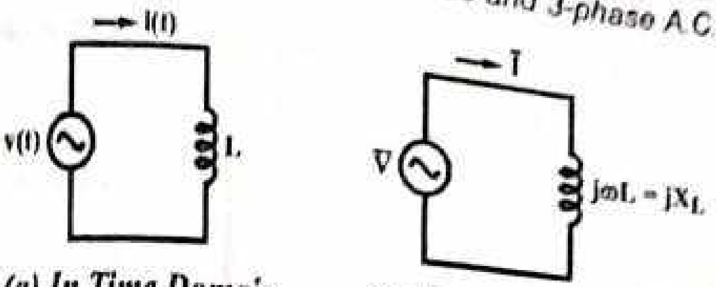
$$= \frac{V_m I_m}{2} 2 \sin \omega t \cos \omega t = \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \sin 2\omega t$$

or Average power $P = 0$

Hence, average power consumed in a pure capacitive circuit is zero. The power curve for this circuit is shown in fig. 2.22 (b).

Q.30. Determine phase angle relationship between alternating voltage and current in a purely inductive and purely capacitive circuit under steady state condition. ***(R.G.P.V., June 2010)***

Ans. Consider an inductance excited by sinusoidal voltage as in fig. 2.23.



(a) In Time Domain *(b) In Frequency Domain-phasor Form*

Fig. 2.23

In time domain

$$v(t) = L\frac{di}{dt}$$

In frequency domain

$$\overline{V}e^{j\omega t} = L\frac{d}{dt}[\overline{I}\, e^{j\omega t}] = j\omega L\overline{I}\, e^{j\omega t}$$

In phasor form $\quad \overline{V} = j\omega L\,\overline{I} = jX_L\,\overline{I}$ ...(i)

where, $X_L = \omega L = 2\pi f L\ \Omega$

In alternative form $\quad \overline{I} = \frac{1}{j\omega L}\overline{V} = -j\frac{1}{X_L}\overline{V} = -jB_L\overline{V}$ ...(ii)

where, $\quad B_L = \frac{1}{\omega L} = \frac{1}{X_L}$

= Inductive susceptance (℧)

The phasor diagram for equations (i) and (ii) are given in fig. 2.24.

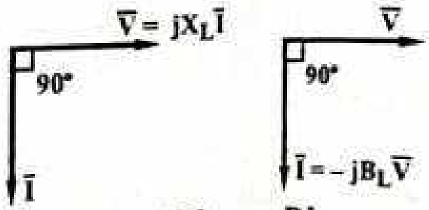
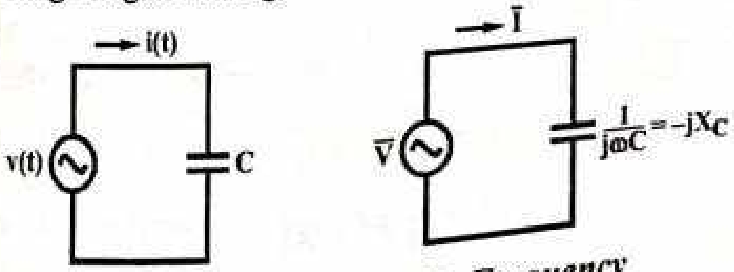


Fig. 2.24 Phasor Diagram

Now consider a capacitance excited by sinusoidal voltage as given in fig. 2.25.



(a) In Time Domain *(b) In Frequency Domain-phasor Form*

Fig. 2.25

In time domain

$$v(t) = \frac{1}{C}\int i(t)\, dt$$

In frequency domain

$$\overline{V}e^{j\omega t} = \frac{1}{C}\int \overline{I}\, e^{j\omega t}dt = \frac{1}{j\omega C}\overline{I}e^{j\omega t}$$

In phasor form

$$\overline{V} = \frac{1}{j\omega C}\overline{I} = -j\frac{1}{\omega C}\overline{I} = -jX_C\overline{I} \qquad ...(iii)$$

where, $X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$

equation (iii) is also expressed as

$$\overline{I} = j\omega C\overline{V} = jB_C\overline{V} \qquad ...(iv)$$

where, $B_C = \omega C$ = Capacitive susceptance (℧)

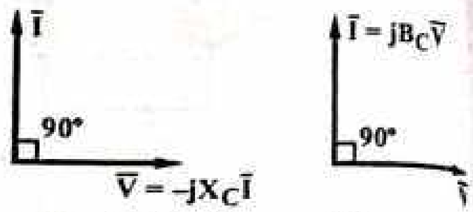


Fig. 2.26 Phasor Diagram

The phasor diagram of equations (iii) and (iv) are given in fig. 2.26.

Q.31. Derive the expression of impedance, admittance and conductance of R-L series circuit. ***(R.G.P.V., Jan./Feb. 2006)***

Ans. An R-L series circuit consists of a pure resistance R (in ohm) connected in series with a pure inductance L (in henry). Fig. 2.27 shows the R-L series circuit.

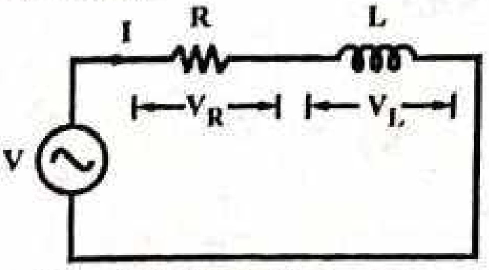


Fig. 2.27 R-L Series Circuit

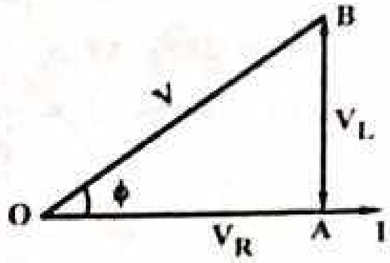


Fig. 2.28 Voltage Triangle

where,

R and L are the resistance and inductance, whereas V, I are the r.m.s values of voltage and current respectively.

Phasor diagram for R-L circuit is shown in the fig. 2.28. OA represents voltage drop in resistance which is in phase with current, and AB represents voltage drop in inductance, whereas, V is the resultant voltage which is given as

$$V = \sqrt{V_R^2 + V_L^2} = \sqrt{(IR)^2 + (I.X_L)^2}$$

or

$$V = I\sqrt{R^2 + X_L^2}$$

$$\frac{V}{I} = \sqrt{R^2 + X_L^2}$$

or

$$Z = \sqrt{R^2 + X_L^2} \qquad ...(i)$$

where, Z is the impedance of circuit

The admittance of an A.C. circuit is defined as the reciprocal of its impedance and is represented by Y.

i.e.,

$$Y = \frac{1}{Z}\ ℧\ (\text{mho}) = \frac{1}{\sqrt{R^2 + X_L^2}}\ \text{mho}$$

In above equation, X_L represents the reactance of the inductor L and is given by

$$X_L = \omega L$$

where L is the inductance of the inductor and ω is the frequency.

Also we know that conductance $= \dfrac{1}{\text{Resistance}} = \dfrac{1}{R}$ ohm^{-1}

Q.32. In a series R-L circuit explain the terms power factor, active power, reactive power and apparent power by drawing the following –

(i) Impedance triangle (ii) Power triangle.

(R.G.P.V., June 2009)

Ans. The impedance equation of a series R-L circuit is given as –

$$Z = \sqrt{R^2 + X_L^2}$$

or $$Z^2 = R^2 + X_L^2$$

Implement this equation of impedance in triangular form as shown in fig. 2.29.

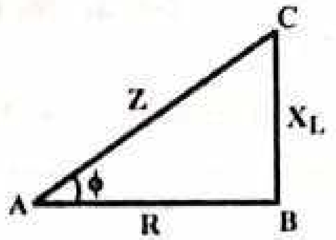


Fig. 2.29 Impedance Triangle

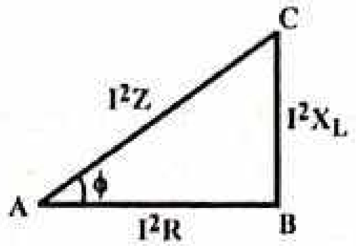


Fig. 2.30 Power Triangle

Power triangle corresponding to impedance triangle is shown in fig. 2.30.

(i) Power Factor – It may be defined as cosine of the angle of lead or lag.

$$\text{P.F.} = \cos\phi$$

$$= \frac{R}{Z} = \frac{P}{S} = \frac{\text{True or active power}}{\text{Apparent power}}$$

(ii) Active Power – It is the power which is actually dissipated in the circuit resistance.

$$P = I^2R = I^2.Z\cos\phi \qquad \left(\because \cos\phi = \frac{R}{Z}\right)$$

$$= IZ.I\cos\phi = VI\cos\phi \text{ Watts} \qquad [\therefore V = IZ]$$

(iii) Reactive Power – It is the power developed in the inductive reactance of the circuit.

$$Q = I^2X_L = I^2.Z\sin\phi \qquad \left(\because \sin\phi = \frac{X_L}{Z}\right)$$

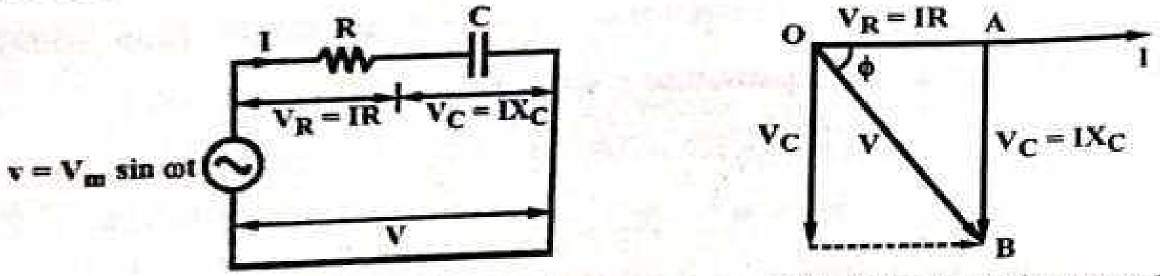
$$= IZ.I\sin\phi = VI\sin\phi \quad \text{VAR}$$

(iv) Apparent Power – It is given by the product of r.m.s. values of applied voltage and circuit current.

$$S = VI = IZ.I = I^2Z \quad VA$$

Q.33. Derive the expression of impedance, admittance phase angle and power of R-C series circuit.

Ans. An R-C series circuit consists of a pure resistance R (in ohm) connected in series with a pure capacitance C (in farad). Fig. 2.31 (a) shows the R-C series circuit and fig. 2.31 (b) shows the phasor diagram of R-C series circuit. V and I are the r.m.s. values of voltage and current respectively.



(a) R-C Series Circuit ***(b) Phasor Diagram of R-C Series Circuit***

Fig. 2.31

Here, $V_R = IR$ = Voltage drop across R in phase with I

$V_C = IX_C$ = Voltage drop across capacitor lagging I by 90°

The resultant voltage V is equal to the vector sum of these two voltage drops i.e.,

$$V = \sqrt{V_R^2 + V_C^2}$$

$$= \sqrt{(IR)^2 + (IX_C)^2} = I\sqrt{R^2 + X_C^2}$$

$$\frac{V}{I} = \sqrt{R^2 + X_C^2} = Z \quad \text{...(i)}$$

where, $Z = \sqrt{R^2 + X_C^2}$, is the impedance of the circuit and it is measured in ohms.

The admittance Y of an A.C. circuit is defined as the reciprocal of its impedance i.e.,

$$Y = \frac{1}{Z} = \frac{1}{\sqrt{R^2 + X_C^2}} \text{ mho} \quad \text{...(ii)}$$

In equation (ii), X_C represents the capacitive reactance and is given by

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

where C is the capacitance of the capacitor and ω is the frequency.

From fig. 2.31 (b), the phase angle is given by

$$\tan\phi = \frac{V_C}{V_R} = \frac{IX_C}{IR} = \frac{X_C}{R} \quad \text{or } \phi = \tan^{-1}\left(\frac{X_C}{R}\right)$$

If the alternating voltage applied across the circuit is given by

$$v = V_m \sin \omega t$$

and $$i = I_m \sin(\omega t + \phi)$$

Then, instantaneous power is given by

$$p = vi$$
$$= V_m \sin \omega t . I_m \sin(\omega t + \phi)$$
$$= \frac{V_m I_m}{2} 2\sin(\omega t + \phi).\sin\omega t$$
$$= \frac{V_m I_m}{2}[\cos(\omega t + \phi - \omega t) - \cos(\omega t + \phi + \omega t)]$$
$$= \frac{V_m I_m}{2}[\cos\phi - \cos(2\omega t + \phi)]$$
$$= \frac{V_m I_m}{2}\cos\phi - \frac{V_m I_m}{2}\cos(2\omega t + \phi)$$
$$= \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos\phi - \frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos(2\omega t + \phi)$$

Average power consumed in the circuit over a complete cycle i.e. the second term $\frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos(2\omega t + \phi)$ is equal to zero. Then,

$$P = V_{r.m.s.}\, I_{r.m.s.} \cos\phi - 0 \qquad \left[\frac{V_m}{\sqrt{2}} = V_{r.m.s.}, \frac{I_m}{\sqrt{2}} = I_{r.m.s.}\right]$$

$$= V_{r.m.s.}\, I_{r.m.s.} \cos\phi$$

or $$P = VI\cos\phi$$

where $\cos\phi$ is the power factor of the circuit.

The waveform for voltage and current is shown in fig. 2.32.

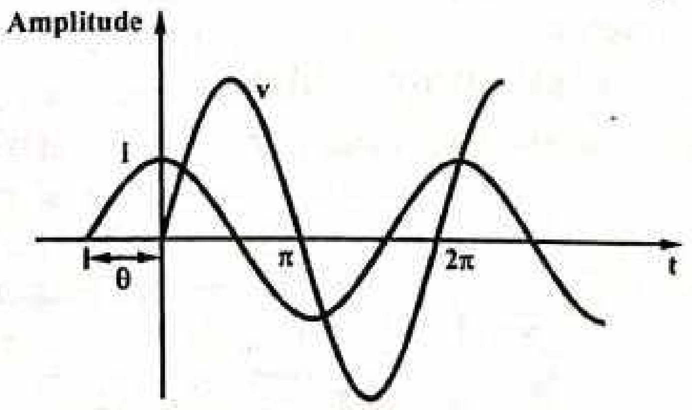


Fig. 2.32 Waveform for Voltage and Current in Series R-C Circuit

Q.34. Obtain an expression for the power factor of a composite series circuit containing a resistance, an inductance and a capacitance.

(R.G.P.V., Dec. 2008)

Ans. An A.C. circuit in which resistance R, inductance L and the capacitance C are connected in series as shown in fig. 2.33 is called series R.L.C. A.C circuit. An A.C. supply at a frequency f hertz is applied to the circuit.

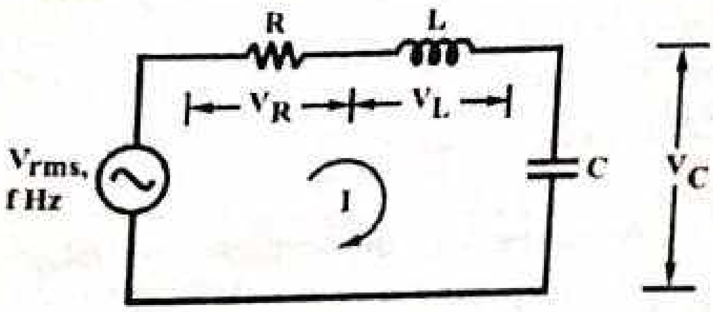


Fig. 2.33 R-L-C Series Circuit

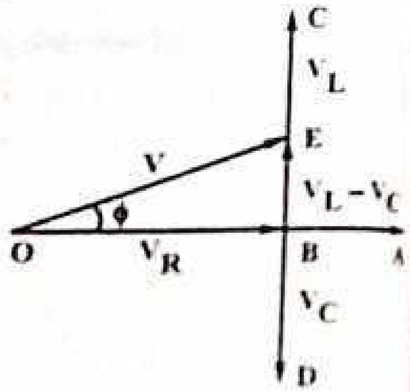


Fig. 2.34 Phasor Diagram of R-L-C Series Circuit ($V_L > V_C$)

Let V = r.m.s. value of the voltage applied to the circuit

V_R = r.m.s. value of the voltage across the resistance R

V_L = r.m.s. value of the voltage across the inductance L

V_C = r.m.s. value of the voltage across the capacitance C

I = r.m.s. value of the current flowing through the circuit.

The phasor diagram of this circuit can be drawn by taking the r.m.s value of current as a reference phasor. It is represented in fig. 2.34, by OA. The voltage drop V_R across the resistor R is in phase with the current and is represented by OB. The voltage V_L across the inductance L leads the current phasor by 90° (BC). The voltage V_C across the capacitor lags the current by 90° and is shown by phasor BD. Phasors BC and BD are in direct opposition and hence their resultant is given by, BE = BC – BD [assume BC > BD]. Hence the applied voltage will be the phasor sum of the phasor OB and BE, say OE from the phasor diagram,

$$(OE)^2 = (OB)^2 + (BE)^2$$

$$V^2 = V_R^2 + (V_L - V_C)^2 \qquad \{\because BE = BC - BD\}$$

$$V = \sqrt{(IR)^2 + (IX_L - IX_C)^2}$$

or
$$V = I\sqrt{R^2 + (X_L - X_C)^2}$$

or
$$\frac{V}{I} = Z = \sqrt{R^2 + (X_L - X_C)^2} \qquad ...(i)$$

Equation (i) gives the circuit impedance. And by definition, admittance is the inverse of impedance i.e.,

$$Z = \frac{1}{Y}$$

or
$$Y = \frac{1}{Z} = \frac{1}{\sqrt{R^2 + (X_L - X_C)^2}} \quad ...(ii)$$

where R is the resistance of the resistor and the reciprocal of the resistance is the conductance

i.e.,
$$\text{Conductance} = \frac{1}{R}\ \text{ohm}^{-1} \quad ...(iii)$$

and $X_L - X_C = X$, denotes the resultant reactance of the series R-L-C circuit.

Therefore, by the definition of the susceptance the reciprocal of resultant reactance is called the susceptance. We can write

$$\text{Susceptance} = \frac{1}{X} = \frac{1}{X_L - X_C} = \frac{1}{\left(\omega L - \frac{1}{\omega C}\right)} \quad ...(iv)$$

Since the voltage drop across the inductance has been assumed greater than the voltage across the capacitance, the resultant circuit becomes inductive. Hence the current in the circuit lags the applied voltage by an angle ϕ. The power factor of such a circuit is then lagging. The angle of lag ϕ is given by

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) = \tan^{-1}\left[\frac{\text{Resultant reactance}}{\text{Resistance}}\right]$$

Power factor of the circuit,

$$\cos\phi = \frac{R}{Z} = \frac{\text{Resistance}}{\text{Impedance}} = \frac{R}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} \quad ...(v)$$

Q.35. Discuss various characteristic of a series RLC circuit. Derive mathematical expression in support of your discussion. (R.G.P.V., Dec. 2017)

***Ans.* Three Cases of R-L-C Series Circuit –**

(i) The phase angle ϕ is positive when $X_L > X_C$. In effect, the circuit acts as an R-L series circuit. The circuit current lags behind the applied voltage and power factor is lagging. The current equation is,

$$i = I_m \sin(\omega t - \phi)$$

(ii) The phase angle ϕ is negative if $X_L < X_C$. In effect, the circuit acts as an R-C circuit. The circuit current leads the applied voltage and power factor is leading. The current equation is

$$i = I_m \sin(\omega t + \phi)$$

(iii) The phase angle ϕ is zero if $X_L = X_C$. In effect, the circuit acts like a pure resistive circuit. The circuit current is in phase with supplied voltage and power factor is unity. The current equation is given by

$$i = I_m \sin \omega t$$

Refer the ans. of Q.34.

Q.36. Write short note on R-L parallel circuit.

Ans. A steady state parallel R–L circuit is shown in fig. 2.35 and excited by a sinusoidal voltage source is.

$$v = V_m \sin \omega t$$

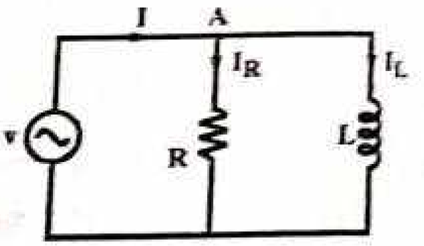


Fig. 2.35 R-L Parallel Circuit

At steady state,

$$I_R = \frac{V}{R}$$

and
$$I_L = \frac{V}{jX_L} = \frac{V}{j\omega L}$$

Thus, by KCL

$$I = I_R + I_L \quad \text{...(i)}$$

$$= \frac{V}{R} + \frac{V}{j\omega L}$$

$$= V\left(\frac{1}{R} + \frac{1}{j\omega L}\right) = VY \quad \text{...(ii)}$$

where, Y is admittance = G + jB

where, G = Conductance = $\frac{1}{R}$ mho

and B = Inductance susceptance = $\frac{1}{X_L}$ mho

Then $Y = G + jB$

$$= \frac{1}{R} + \frac{1}{jX_L} = \frac{1}{R} + \frac{1}{j\omega L} = \frac{1}{R} - j\frac{1}{\omega L} \quad \text{...(iii)}$$

The net current supplied from the source in steady state lags, the voltage by impedance angle is expressed as follows –

$$\tan\theta = -\frac{1/\omega L}{1/R} = \left(-\frac{R}{\omega L}\right)$$

$$\theta = \tan^{-1}\left(-\frac{R}{\omega L}\right) \quad \text{...(iv)}$$

Again,

$$i = i_R + i_L = \frac{v}{R} + \frac{1}{L}\int v\, dt$$

Let $v = V_m \cos \omega t$

Then, $i = \frac{V_m}{R}\cos\omega t + \frac{V_m}{L}\int \cos\omega t\, dt = \frac{V_m}{R}\cos\omega t + \frac{V_m}{\omega L}\sin\omega t$

$$\therefore \quad i = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{\omega L}\right)^2}\, V_m \cos(\omega t - \theta) \quad ...(v)$$

When θ is given by equation (iv).

If $R >> \omega L$, $\theta \to 90°$ and $i \simeq i_L = \frac{V_m}{\omega L}\cos(\omega t - 90°)$

and if $R << \omega L$, $\theta \to 0°$ and $i \simeq i_R = \frac{V_m}{R}\cos\omega t$.

Q.37. Explain R-C parallel circuit.

Ans. A steady state R-C parallel circuit is shown in fig. 2.36 and excited by sinusoidal voltage source $v = V_m \sin \omega t$. At steady state,

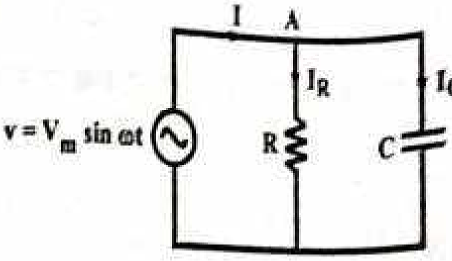


Fig. 2.36 R-C Parallel Circuit

$$I_R = \frac{V}{R} \text{ and } I_C = \frac{V}{jX_C} = \frac{V}{1/j\omega C}$$

However, applying Kirchhoff's current law at node A,

$$I = I_R + I_C$$

$$= \frac{V}{R} + \frac{V}{1/j\omega C} = V\left[\frac{1}{R} + \frac{1}{1/j\omega C}\right] = V\left[\frac{1}{R} + j\omega C\right] = VY \quad ...(i)$$

[$\because$ Y = admittance = G + jB; where, G = conductance = 1/R mho, B = capacitance susceptance = $j\omega C$ mho]

Here, $Y = \frac{1}{R} + j\omega C$ and $\tan\theta = \frac{\omega C}{1/R} = (\omega RC)$

$$\theta = \tan^{-1}(\omega RC) \quad ...(ii)$$

Hence, it is clear that the current leads the voltage by an angle given by equation (ii),

Again, as $i = i_R + i_C$, we can write

$$i = \frac{v}{R} + C\frac{dv}{dt} = \frac{V_m \sin\omega t}{R} + C\frac{d}{dt}[V_m \sin\omega t]$$

$$= \frac{V_m}{R}\sin\omega t + V_m C\cos\omega t.\omega = \frac{V_m}{R}\sin\omega t + \omega C V_m \cos\omega t$$

$$\therefore \quad i = \sqrt{\left(\frac{1}{R}\right)^2 + (\omega C)^2}\, V_m \sin(\omega t + \theta) \quad ...(iii)$$

If $R >> \frac{1}{\omega c}$, $\theta \to 90°$ and $i = i_C = \omega C V_m \sin(\omega t + 90°)$ and if $R << \frac{1}{\omega C}$

$\theta \to 0°$ and $i = i_R = \frac{V_m}{R} \sin \omega t$.

Q.38. Obtain current I in the given R-L-C parallel circuit under resonance condition. Justify your answer.

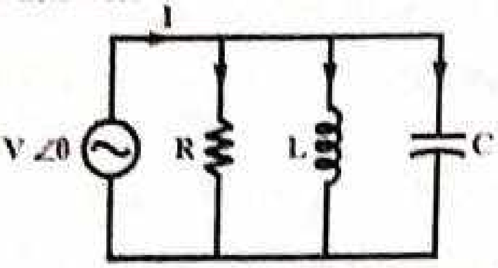


Fig. 2.37 ***(R.G.P.V., June 2013)***

Ans. A steady state parallel R.L.C. circuit is shown in fig. 2.38, being excited by a voltage sinusoid $v = V_m \sin \omega t$.

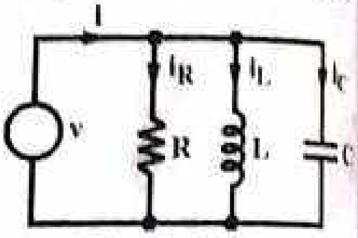


Fig. 2.38 Parallel R.L.C. Circuit

Here, $i = i_R + i_L + i_C$

$$= \frac{v}{R} + \frac{1}{L}\int v\,dt + C\frac{dv}{dt}$$

$$= \frac{V_m}{R}\sin \omega t - \frac{V_m}{\omega L}\cos \omega t + \omega C\,V_m \cos \omega t \quad ...(i)$$

Let $i = A\sin(\omega t + \theta) = A\sin \omega t \cos\theta + A\cos \omega t \sin\theta \quad ...(ii)$

Equating the coefficient of sin ωt and cos ωt in equations (i) and (ii), we have

$$\frac{V_m}{R} = A\cos\theta \text{ and } \left(\omega C - \frac{1}{\omega L}\right)V_m = A\sin\theta$$

Then
$$\tan\theta = \frac{\omega C - \frac{1}{\omega L}}{1/R} \quad ...(iii)$$

$$\cos\theta = \frac{1/R}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\omega C - \frac{1}{\omega L}\right)^2}} \quad ...(iv)$$

$$A = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\omega C - \frac{1}{\omega L}\right)^2}\,.V_m \quad ...(v)$$

and $$i = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\omega C - \frac{1}{\omega L}\right)^2}\,.V_m \sin\left[\omega t + \tan^{-1}\left(\omega C - \frac{1}{\omega L}\right)R\right] \quad ...(vi)$$

Obviously, the sign of the phase angle θ depends on the relative values of ωC and $1/\omega L$.

It should be noted that the inductive branch current I_L is at 90° lagging the supply voltage while the capacitive branch currents I_C is at 90° leading the supply voltage. With proper selection of L and C, these two currents I_L and I_C may mutually cancel each other and the total current can be resistive only. However, if the capacitive current is predominant, i, the total current would be capacitive and if the inductive current I_L is predominant, the total current i would be inductive.

Q.39. Draw and explain the R-L-C series and parallel circuit.
(R.G.P.V., May 2019)

Ans. Refer the ans. of Q.34 and Q.38.

Q.40. Describe the series resonance of R-L-C circuit and list its important properties. ***(R.G.P.V., June 2004, 2005)***

Or

Derive an expression for series resonance of a R-L-C series A.C. circuit.
(R.G.P.V., June 2016)

Ans. **Resonance** – Resonance in electrical circuits consisting of passive and active elements represent a particular state of the circuit. When the current or voltage in the circuit is maximum with respect to magnitude of excitation at a particular frequency, the circuit impedance being minimum at unity power factor and vice-versa.

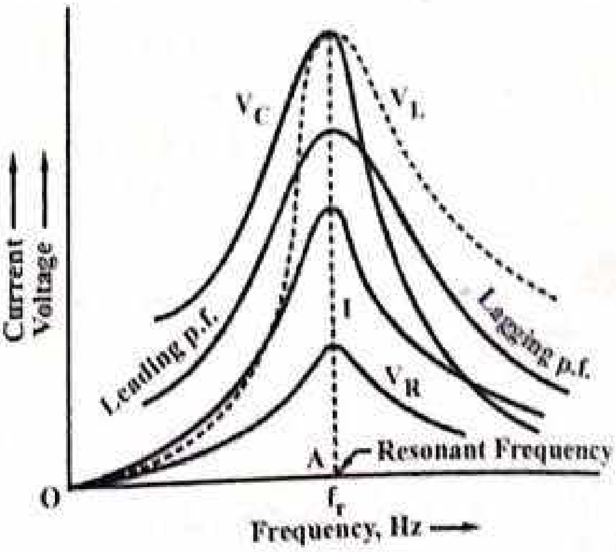


Fig. 2.39 Effect of Frequency on Voltage, Current and Power Factor

Fig. 2.39 shows the condition of resonance, behaviour of voltage and current verses frequency can be represented.

As shown in fig. 2.39, at resonance frequency, voltage across inductance and capacitance have equal and maximum value, which may be many times greater than the applied voltage, but this voltage drop being equal and opposite.

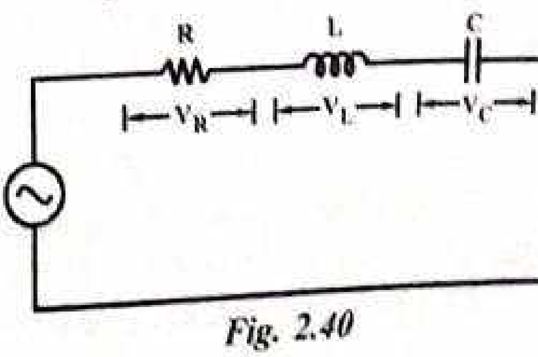


Fig. 2.40

A series R-L-C circuit shown in fig. 2.40, where R, L, C are pure resistance, inductance and capacitance and V_R, V_L, V_C are voltage drops in them.

Let such a circuit be connected across an A.C. source of constant voltage but a varying frequency, which is varying from zero to infinity. There would be a certain frequency at which inductive reactance equal to capacitive reactance. In that case X = 0 and Z = R, and circuit is said to be in electrical resonance.

Capacitive reactance $X_C = \frac{1}{2\pi f_0 C}$ and inductive reactance, $X_L = 2\pi f_0 L$

where f_0 = Resonant frequency.

At resonance, $X_L = X_C$

$$\therefore \quad 2\pi f_0 L = \frac{1}{2\pi f_0 C} \text{ or } f_0 = \frac{1}{2\pi\sqrt{LC}}$$

If L is in henry and C is in farad then f_0 given in Hz.

Q-factor of coil in series resonance

$$Q = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 CR} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Properties of Resonance of R-L-C Series Circuit –

(i) The applied voltage and the resulting current are in phase i.e., the power factor of the R-L-C series resonant circuit is unity.

(ii) The net reactance is zero at resonance and the impedance does have the resistive part only.

(iii) The current in the circuit is maximum and is (V/R) A. [Since at resonance, the line current in the series R-L-C circuit is maximum hence it is called ***acceptor circuit***.]

(iv) At resonance, the circuit has got minimum impedance and maximum admittance.

(v) Frequency of resonance is given by $f_0 = \frac{1}{2\pi\sqrt{LC}}$ Hz.

Q.41. Derive the formula for resonance frequency in parallel resonance.

Or

Describe parallel resonance and list its important properties.

Ans. Let us consider a case in which a coil connected in parallel with a capacitor as shown in fig. 2.41 (a). And circuit said to be in electrical resonance when reactive component of line current becomes zero.

The frequency in this condition is known as resonant frequency.

Formula for Resonant Frequency – The vector diagram for the circuit in fig. 2.41 (a) is shown in fig. 2.41 (b).

Net reactive wattless component = $I_C - I_L \sin\phi_L$

At resonance, wattless component should be zero, hence

$$I_C - I_L \sin\phi_L = 0$$

or
$$I_L \sin\phi_L = I_C$$

Now
$$I_L = \frac{V}{Z},\ \sin\phi_L = \frac{X_L}{Z},\ I_C = \frac{V}{X_C}$$

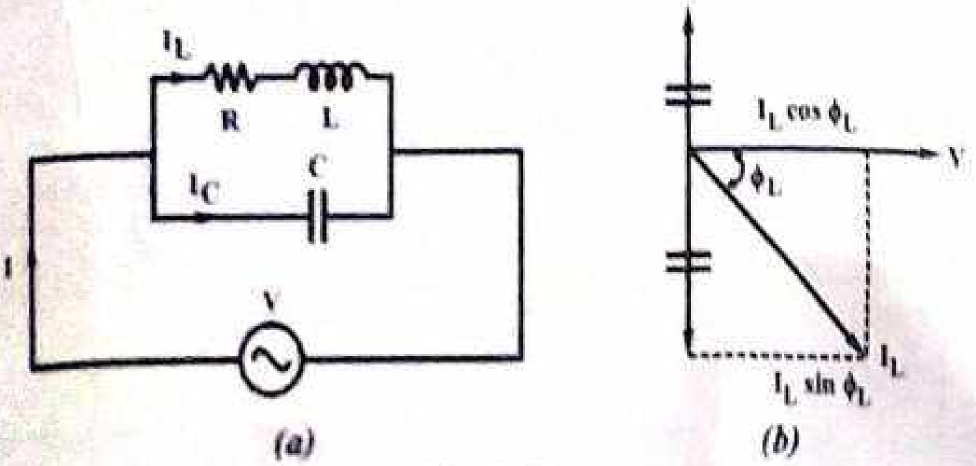


Fig. 2.41

Hence, at resonance

$$\frac{V}{Z} \times \frac{X_L}{Z} = \frac{V}{X_C}$$

or
$$X_L \times X_C = Z^2$$

but,
$$X_L = \omega_0 L,\ X_C = \frac{1}{\omega_0 C},\ Z = \sqrt{R^2 + (\omega_0 L)^2}$$

where, $\omega_0 = 2\pi f_0$

$$\therefore \quad 2\pi f_0 L \times \frac{1}{2\pi f_0 C} = R^2 + (\omega_0 L)^2$$

or
$$\frac{L}{C} = R^2 + 4\pi^2 f_0^2 L^2$$

or
$$4\pi^2 f_0^2 L^2 = \frac{L}{C} - R^2$$

or
$$f_0^2 = \frac{1}{4\pi^2}\left(\frac{1}{LC} - \frac{R^2}{L^2}\right) \text{ or } f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

This is the resonant frequency given in Hz, where L and C are given in henry and farad respectively.

Properties of Resonance of Parallel R-L-C Circuit –

(i) Power factor is unity.

(ii) The value of current at resonance is minimum.

(iii) Net impedance at resonance of the parallel circuit is maximum and equal to (L/CR) Ω.

(iv) The admittance is minimum and the net susceptance is zero at resonance.

(v) The resonance frequency of this circuit is given by

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}.$$

Q.42. Compare the series and parallel resonance.

Ans. Comparison in series and parallel resonance are given below –

S.No.	*Series Circuit (R-L-C)*	*Parallel Circuit (R-L-C)*
(i)	Resonant frequency. $f_0 = \frac{1}{2\pi\sqrt{LC}}$	Resonant frequency. $f_0 = \frac{1}{2\pi}\sqrt{\left(\frac{1}{LC} - \frac{R^2}{L^2}\right)}$
(ii)	Impedance will be minimum at resonance and its effective value will be R.	Impedance will be maximum and its effective value will be L/CR.
(iii)	Power factor will be unity.	Power factor will be unity.
(iv)	Current at resonance have maximum value.	Current at resonance have minimum value.
(v)	It magnifies voltage.	It magnifies current.
(vi)	Magnification in voltage is ωL/R.	Magnification in current is ωL/R.

Q.43. Explain briefly the following as applied to A.C. series and parallel circuits –

(i) Resonance frequency (ii) Q-factor. (R.G.P.V., June 2017)

Ans. (i) Resonance Frequency – Refer the ans. of Q.40 and Q.41.

(ii) Q-factor – For series resonating circuit, Q factor can be expressed as the ratio of the voltage across the capacitor or inductor to the applied voltage. It is also the voltage magnification in the circuit at resonance.

$$Q = \frac{V_C}{V} = \frac{V_L}{V}$$

where V_C denotes the voltage across the capacitor, V_L the voltage across the inductor at resonance and V the applied voltage.

$$Q = \frac{V_C}{V} = \frac{I_0 X_C}{I_0 R} = \frac{X_C}{R} = \frac{1}{\omega_0 CR} \quad \text{(for the capacitor)} \quad ...(i)$$

also $$Q = \frac{V_L}{V} = \frac{I_0 X_L}{I_0 R} = \frac{X_L}{R} = \frac{\omega_0 L}{R} \quad \text{(for the inductor)} \quad ...(ii)$$

Again $V_C = I_0 X_C = \frac{V}{R} \cdot \frac{1}{\omega_0 C} = \frac{1}{\omega_0 RC} \cdot V$

$= \text{Q-factor} \times V$ volts ...(iii)

and $V_L = I_0 X_L = \frac{V}{R} \cdot X_L = \frac{V}{R} \cdot \omega_0 L = \frac{\omega_0 L}{R} \cdot V$

$= \text{Q-factor} \times V$ volts ...(iv)

Also

$$Q = \frac{1}{\omega_0 RC} = \frac{1}{\frac{1}{\sqrt{LC}} \cdot R.C} = \frac{1}{R}\sqrt{\frac{L}{C}} \qquad \left\{\because \omega_0 = \frac{1}{\sqrt{LC}}\right\} \quad ...(v)$$

and also,

$$Q = \frac{\omega_0 L}{R} = \frac{1}{\sqrt{LC}} \cdot \frac{1}{R} = \frac{1}{R}\sqrt{\frac{L}{C}} \quad ...(vi)$$

For parallel circuit, Q-factor is the current magnification of the circuit at resonance. It shows the ratio of the current circulating between the two parallel branches.

i.e.,

$$Q = \frac{I_C}{I} = \frac{V/X_C}{V/Z_\Omega} = \frac{Z_\Omega}{X_C} = \frac{L}{CR} \times \frac{1}{\frac{1}{\omega_0 C}}$$

or

$$Q = \frac{L}{CR} \times \omega_0 C = \frac{\omega_0 L}{R} = Q \text{ factor of series circuit}$$

But $\omega_0 = \frac{1}{\sqrt{LC}}$, then we get

$$\therefore \quad Q = \frac{1}{R}\sqrt{\frac{L}{C}} \quad ...(vii)$$

A parallel resonating circuit is also frequently known as rejector circuit as anti-resonant circuit or tuned circuit.

NUMERICAL PROBLEMS

Prob.4. *In a circuit, the applied voltage is found to lag the current by 30°.*

(i) Is the p.f. lagging or leading ?

(ii) What is the value of power factor ?

(iii) Is the circuit capacitive or inductive ?

(R.G.P.V., Sept. 2009)

Sol. (i) Since the applied voltage lags behind the current or in other words, the current leads the voltage, therefore power factor is leading.

(ii) p.f. = $\cos \phi = \cos 30° = 0.866$ (leading)

(iii) For a capacitive circuit, p.f. is always leading, therefore given circuit is capacitive.

Prob.5. Voltage and current in an A.C. circuit are given as below –

$$v = 50 \sin(\omega t - 30^\circ)$$
$$i = 10 \cos(\omega t - 60^\circ)$$

From above answer the following –

(i) Circuit impedance (ii) Phasor representation of voltage and current
(iii) Power factor (iv) R.M.S. voltage and current
(v) Apparent power.

(R.G.P.V., March/April 2010)

Sol. Convert the current i into sinusoidal form as,

$$i = 10 \sin(\omega t - 60^\circ + 90^\circ) = 10 \sin(\omega t + 30^\circ)$$

and given voltage $v = 50 \sin(\omega t - 30^\circ)$

Hence, the polar representation of current i and voltage v are as given below

$$I_{r.m.s.} = I = \frac{10}{\sqrt{2}} \angle 30^\circ = 7.07 \angle 30^\circ \text{ A}$$

$$V_{r.m.s.} = V = \frac{50}{\sqrt{2}} \angle -30^\circ = 35.4 \angle -30^\circ \text{ V}$$

(i) Circuit Impedance –

$$Z = \frac{V}{I} = \frac{50\sqrt{2} \angle -30^\circ}{10\sqrt{2} \angle 30^\circ} = \mathbf{5 \angle -60^\circ} \qquad \textbf{Ans.}$$

(ii) Phasor Representation of Voltage and Current –

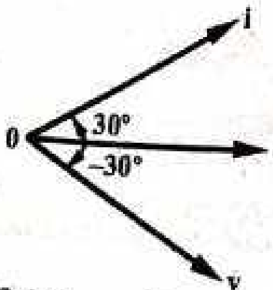


Fig. 2.42 Phasor Representation

(iii) Power Factor –

$$\text{p.f.} = \cos \phi$$

where ϕ is angle between voltage and current that is 60°.

$\therefore$

$$\text{p.f.} = \cos 60^\circ = 0.5 \text{ (leading)}$$

(iv) R.M.S. Voltage and Current –

$$V_{r.m.s.} = V = \frac{50}{\sqrt{2}} \angle -30^\circ = \mathbf{35.4 \angle -30^\circ \text{ V}} \qquad \textbf{Ans.}$$

$$I_{r.m.s.} = I = \frac{10}{\sqrt{2}} \angle 30^\circ = \mathbf{7.07 \angle 30^\circ \text{ A}} \qquad \textbf{Ans.}$$

(v) Apparent Power –

$$S = V_{r.m.s.} I_{r.m.s.} \text{ VA}$$
$$= 35.4 \angle -30^\circ \times 7.07 \angle 30^\circ = \mathbf{250.3 \text{ VA}} \qquad \textbf{Ans.}$$

Prob.6. A coil takes 2.5 amps. when connected across 200 volts 50 Hz mains. The power consumed by the coil is found to be 400 watts. Find the inductance and the power factor of the coil. *(R.G.P.V., June 2017)*

Sol. Current taken by the coil, I = 2.5 A

Applied voltage V = 200 volts

Power consumed P = 400 watts

Power consumed by the coil is given as

$$P = VI \cos \phi$$

or
$$\cos \phi = \frac{P}{VI} = \frac{400}{200 \times 2.5} = 0.8$$

Thus, power factor of coil is **0.8**. **Ans.**

We know that, impedance of the coil is,

$$Z = \frac{V}{I} = \frac{200}{2.5} = 80\,\Omega$$

Also
$$\frac{X_L}{Z} = \sin \phi$$

$\therefore$
$$X_L = Z \sin \phi$$
$$= Z\sqrt{1-\cos^2 \phi} = 80\sqrt{1-(0.8)^2} = 48\,\Omega$$

But
$$X_L = 2\pi f L$$

or
$$L = \frac{X_L}{2\pi f} = \frac{48}{2\pi \times 50} = \mathbf{0.1528\ H}$$ **Ans.**

Prob.7. A coil of resistance 10 Ω and inductance 0.1 H is connected in series with 150 µF capacitor across a 200 V, 50 Hz supply. Calculate –

(i) Inductive reactance ***(ii) Capacitive reactance***

(iii) Impedance ***(iv) Current***

(v) Power factor ***(vi) Voltage across the coil***

(vii) Voltage across capacitor.

(R.G.P.V., Dec. 2013, 2016)

Sol. Given,
$$R = 10\,\Omega,\ L = 0.1\ H,\ C = 150\ \mu F$$
$$V = 200\ V,\ f = 50\ Hz$$

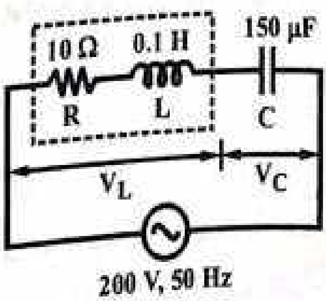


Fig. 2.43

The circuit is shown in fig. 2.43.

(i) Inductive reactance –

$$X_L = \omega L = 2\pi f L$$
$$= 2 \times 3.14 \times 50 \times 0.1$$
$$= \mathbf{31.4\ \Omega}$$ **Ans.**

(ii) Capacitive reactance –

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC} = \frac{1}{2 \times 3.14 \times 50 \times 150 \times 10^{-6}} = 21.23\ \Omega$$ Ans.

(iii) Impedance –

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$= \sqrt{(10)^2 + (31.4 - 21.23)^2}$$
$$= \sqrt{100 + 103.43} = \mathbf{14.26\ \Omega}$$ Ans.

(iv) Current –

$$I = \frac{V}{Z} = \frac{200}{14.26} = \mathbf{14.03\ A}$$ Ans.

(v) Power factor –

$$\cos\phi = \frac{R}{Z} = \frac{10}{14.26} = \mathbf{0.70\ (lag)}$$ Ans.

(vi) Impedance across the coil,

$$Z_L = \sqrt{R^2 + X_L^2} = \sqrt{10^2 + 31.4^2} = 32.95\ \Omega$$

Voltage across the coil,

$$V_L = IZ_L$$
$$= 14.03 \times 32.95 = \mathbf{462.3\ V}$$ Ans.

(vii) Voltage across capacitor –

$$V_C = I\,X_C$$
$$= 14.03 \times 21.23 = \mathbf{297.86\ V}$$ Ans.

Prob.8. A 220 volt, 50 Hertz supply is given to a series RLC circuit having a resistance of 50 ohm, inductance of 0.2 henry and capacitance of 100 microfarad. Calculate impedance, current in the circuit and voltage across R, L, C. *(R.G.P.V., May 2018)*

Sol. Given, $V = 220\ V,\ f = 50\ Hz$
$R = 50\ \Omega,\ L = 0.2\ H,\ C = 100\ \mu F = 100 \times 10^{-6}\ F$

The circuit is shown in fig. 2.44.

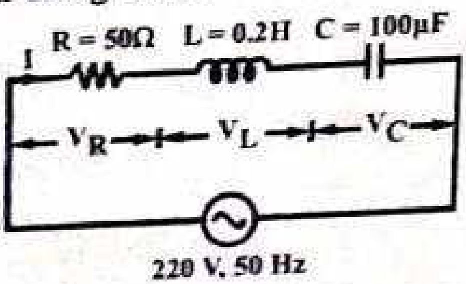


Fig. 2.44

Inductive reactance is given by

$$X_L = \omega L = 2\pi fL$$
$$= 2 \times 3.14 \times 50 \times 0.2$$
$$= 62.8\ \Omega$$

Capacitive reactance is given by

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$$
$$= \frac{1}{2\times 3.14\times 50\times 100\times 10^{-6}}$$
$$= 31.85\ \Omega$$

The impedance is given by

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$= \sqrt{50^2 + (62.8 - 31.85)^2}$$
$$= \sqrt{2500 + 957.9025}$$
$$= \sqrt{3457.9025}$$
$$= \mathbf{58.80\ \Omega}$$

Ans.

The current is given by

$$I = \frac{V}{Z} = \frac{220}{58.80} = \mathbf{3.74\ A}$$ Ans.

Voltage across resistor R is

$$V_R = IR$$
$$= 3.74 \times 50 = \mathbf{187\ V}$$ Ans.

Voltage across inductance L is

$$V_L = IX_L$$
$$= 3.74 \times 62.8 = \mathbf{234.87\ V}$$ Ans.

Voltage across capacitance C is

$$V_C = IX_C$$
$$= 3.74 \times 31.85 = \mathbf{119.12\ V}$$ Ans.

Prob.9. Obtain resultant voltage when two sources of e.m.f.s. having $e_1 = 100 \sin \omega t$ and $e_2 = 100 \sin\left(\omega t - \frac{\pi}{6}\right)$ are connected in series. If resultant voltage is applied to circuit of impedance $(8 + j3)\Omega$, calculate the power (active) supplied to the impedance. *(R.G.P.V., June 2013)*

Sol. Let us draw the two vectors representing values of given alternating voltages, where X-axis taken as reference.

$e_1 = 100 \sin \omega t$, e_1 has zero phase angle with X-axis

$e_2 = 100 \sin (\omega t - 30)$, its vector will be below the X-axis by 30°

Impedance of the circuit,

$$Z = 8 + j3$$
$$= 8.54 \angle 20.55°$$

Resolving the vector shown in fig. 2.45 (a) into X and Y-component, we get

$$\text{X-component} = 100 + 100 \cos 30°$$
$$= 186.60 \text{ volts}$$
$$\text{Y-component} = 100 \sin 30° = 50 \text{ volts}$$

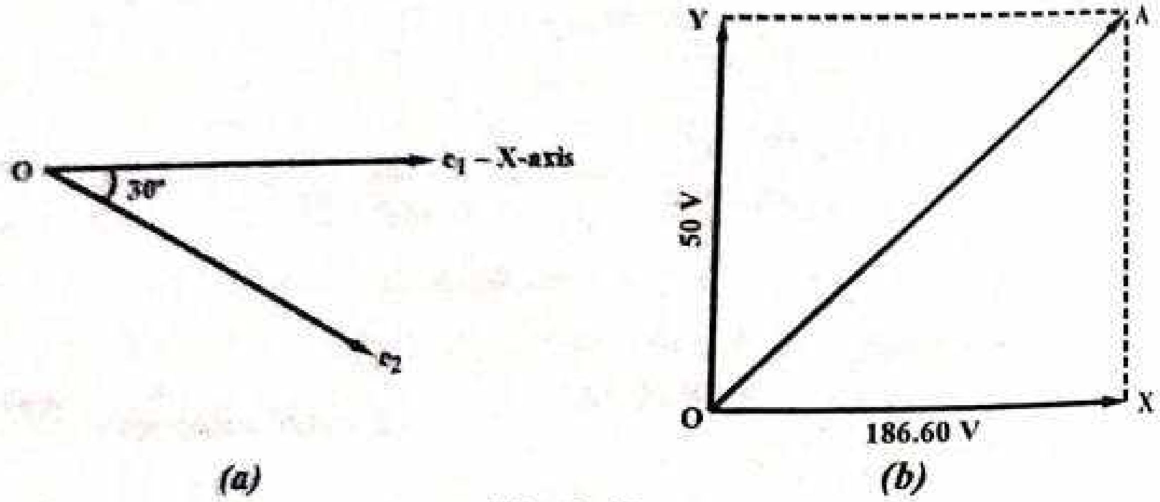


Fig. 2.45

From the fig. 2.45 (b) the maximum value of resultant voltage is,

$$OA = \sqrt{186.60^2 + 50^2}$$
$$= 193.18 \text{ volts}$$

The phase angle of resultant voltage is,

$$\tan \phi = \frac{\text{Y-component}}{\text{X-component}}$$

$$\phi = \tan^{-1}\left(\frac{50}{186.60}\right) = 15°$$

Resultant voltage is $V = 193.18 \angle 15°$

Resultant current is $I = \frac{V}{Z} = \frac{193.18\angle 15°}{8.54 \angle 20.55°} = 22.62 \angle -5.55°$

Power factor of the circuit

$$\cos \phi = \frac{R}{Z} = \frac{8}{8.54} = 0.94$$

$$\text{Power} = VI \cos \phi$$
$$= 193.18 \times 22.62 \times 0.94$$
$$= \mathbf{4107.55 \text{ watt}}$$

Ans.

Prob.10. Two impedances of $Z_1 = 8 + j6$ and $Z_2 = 3 - j4$ are in parallel. If the total current of the combination is 25 A. Find the current taken and power taken by each impedance. *(R.G.P.V., Dec. 2015)*

Sol. Given, $Z_1 = 8 + j6 = 10 \angle 36.87^\circ\ \Omega$

and $Z_2 = 3 - j4 = 5 \angle -53.1^\circ\ \Omega$

Total impedance is given by

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

$$= \frac{(10\angle 36.87^\circ) \times (5\angle -53.1^\circ)}{10\angle 36.87^\circ + 5\angle -53.1^\circ}$$

$$= \frac{50\angle -16.23^\circ}{11.18\angle 10.3^\circ}$$

$$= 4.47 \angle -26.53^\circ\ \Omega$$

Consider, $I = 25 \angle 0^\circ$ A

$$V = IZ = 25 \angle 0^\circ \times 4.47 \angle -26.53^\circ$$

$$= 111.75 \angle -26.53^\circ \text{ volt}$$

$$I_1 = \frac{V}{Z_1} = \frac{111.75\angle -26.53^\circ}{10\angle 36.87^\circ} = 11.175 \angle -63.4^\circ \text{ amp.}$$ **Ans.**

$$I_2 = \frac{V}{Z_2} = \frac{111.75\angle -26.53^\circ}{5\angle -53.1^\circ} = \mathbf{22.35 \angle 26.57^\circ \text{ amp.}}$$ **Ans.**

Now, the phase difference between V and I_1 is,

$$\phi_1 = 63.4 - 26.53^\circ = 36.87^\circ \text{ with current lagging}$$

Therefore, $\cos \phi_1 = \cos 36.87^\circ = 0.8$

Power consumed in Z_1 impedance,

$$= VI_1 \cos \phi_1$$

$$= 111.75 \times 11.175 \times 0.8$$

$$= 999.045$$

$$\simeq \mathbf{999\ W}$$ **Ans.**

Similarly, the phase difference between V and I_2 is,

$$\phi_2 = 26.57^\circ - (-26.53^\circ)$$

$$= 26.57^\circ + 26.53^\circ$$

$$= 53.1^\circ$$

Therefore, $\cos \phi_2 = \cos 53.1^\circ = 0.6$

Power consumed in Z_2 impedance,

$$= VI_2 \cos \phi_2$$

$$= 111.75 \times 22.35 \times 0.6$$ **Ans.**

$$= \mathbf{1499\ W}$$

3-PHASE A.C. CIRCUITS – NECESSITY AND ADVANTAGES OF THREE PHASE SYSTEMS, MEANING OF PHASE SEQUENCE BALANCED AND UNBALANCED SUPPLY AND LOADS, RELATIONSHIP BETWEEN LINE AND PHASE VALUES FOR BALANCED STAR AND DELTA CONNECTIONS

Q.44. What do you mean by 3-phase (3-ϕ) system ?

Ans. A three phase system consists of three independent windings displaced by 120° electrical from each other or, 3-ϕ system may considered as three separate single phase systems displaced from each other by 120° electrical.

Fig. 2.46 represents graphical configuration of 3-ϕ system voltage.

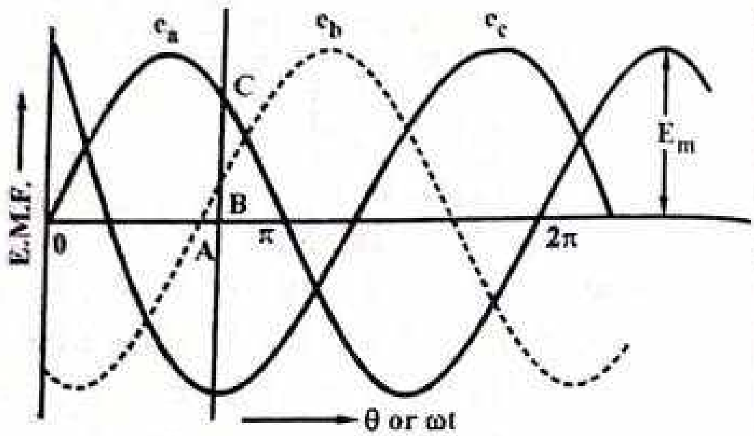


Fig. 2.46

As shown in fig. 2.46, e.m.fs. e_a, e_b, e_c have sinusoidal waveforms and displaced from each other by 120°, the instantaneous values of three e.m.fs. will be given by following equations –

$$e_a = E_m \sin \omega t$$
$$e_b = E_m \sin (\omega t - 120°)$$
$$e_c = E_m \sin (\omega t - 240°)$$
or
$$= E_m \sin (\omega t + 120°)$$

Q.45. What is the necessity of 3-phase interconnection ?

Ans. In a three-phase system, if the three armature coils of the 3-phase alternator are not interconnected but are kept separate as shown in fig. 2.47, then each phase would need two conductors, the total number of conductors, in that case, being six. It means that each transmission cable would contain six conductors, which will make the whole system complicated and expensive. Hence, the three phase system are generally interconnected which results in substantial saving of copper.

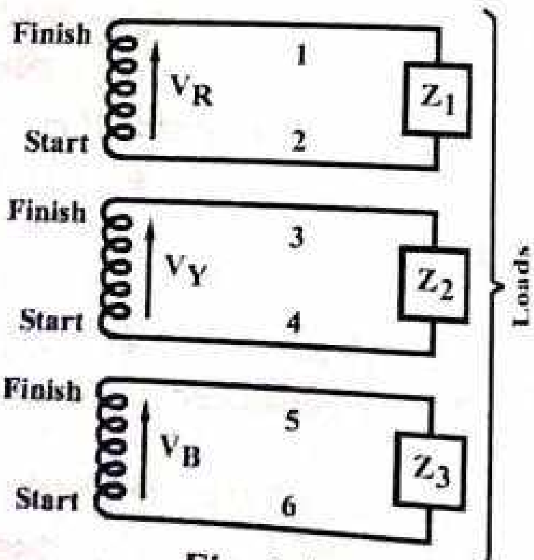


Fig. 2.47

Q.46. Write down the advantages of 3-ϕ system over single phase system. ***(R.G.P.V., June 2016)***

Or

Explain the advantages of three phase system. [R.G.P.V., Nov. 2018(O)]

Ans. Three phase system is preferred over single phase system due to following advantages –

(i) The power delivered in single phase circuit is pulsating. Hence, the power is zero twice in each cycle, even when the voltage and current are in phase. On the other hand, in 3-phase system, the power delivered is almost constant when the loads are balanced.

(ii) The rating of a 3-phase machine is nearly 1.5 times the rating of a single-phase machine of the same size.

(iii) Three phase system requires only 75% of the weight of conducting material to transmit the same amount of power over a fixed distance at a given voltage, of that needed by single-phase system.

(iv) 3-phase machines have better voltage regulation.

(v) Torque produced by three phase motors is more.

(vi) 3-phase machines can be used for domestic as well as commercial purpose.

Q.47. What do you mean by phase sequence in 3-ϕ A.C. voltage waveform, if 3-ϕ A.C. voltage waveform is available to a 3-ϕ motor, then how can we revert the phase sequence, and there by direction of rotation of motor ? ***(R.G.P.V., Dec. 2015)***

Or

Define the phase sequence in 3-ϕ circuit.

Ans. Phase sequence means that the order in which the phase voltages of a 3-phase system attain their maximum positive value.

The phase sequence RYB normally means that the red phase attains maximum value first, then yellow phase and in last blue phase attains the maximum value as illustrated in fig. 2.48. The phase sequence is $R \rightarrow Y \rightarrow B$.

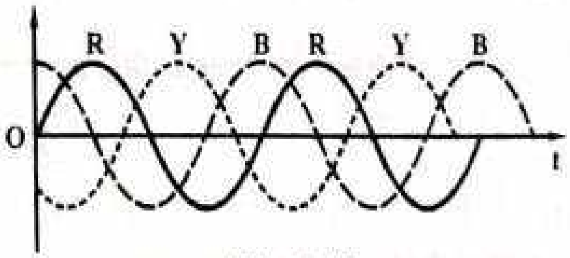


Fig. 2.48

The direction of rotation of 3-ϕ induction motors depends upon the phase sequence of 3-ϕ supply. The phase sequence of the supply given to the motor has to be changed to reverse the direction of rotation.

Q.48. Define –

(i) Impedance and (ii) Phase sequence in A.C. circuit.

(R.G.P.V., Dec. 2014)

Ans.* (i) *Impedance – Refer the ans. of Q.20 (iii).

(ii) Phase Sequence in A.C. Circuit – Refer the ans. of Q.47.

Q.49. Show by a phasor diagram that the sum of the 3-phase balanced current is zero. *(R.G.P.V., June 2002)*

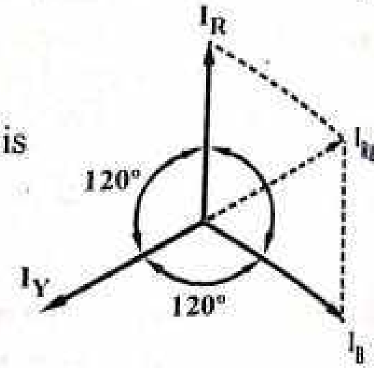
Ans. For a balanced 3-phase system, all phases should have equal maximum values, which are 120° apart in phase with each other as shown in phasor diagram in fig. 2.49.

where, $I_R = I_Y = I_B = I_{ph}$

And resultant of I_B and I_R is I_{RB}, its magnitude is

$$I_{RB} = 2I_{ph} \cos 60^\circ$$

$$= 2I_{ph} \cdot \frac{1}{2} = I_{ph}$$



This resultant I_{RB} is equal and opposite to $I_Y = I_{ph}$

Fig. 2.49

Hence, resultant of their sum will be zero.

Q.50. Differentiate between balanced and unbalanced 3-phase supply and balanced and unbalanced 3-phase load ? *(R.G.P.V., June 2002)*

***Ans.* Balanced and Unbalance 3-phase Supply** – In balanced 3-phase supply, three phase voltage and current must have equal amplitude and equal phase difference between each phases.

Whereas in unbalanced 3-phase supply, current and voltage have either equal or unequal phase difference.

Balanced and Unbalanced 3-phase Load – In a balanced 3-phase load, all phases must have equal impedance and in unbalanced 3-phase load, impedances in one or more phases differ from the impedances of other phases.

Q.51. Explain in brief balanced and unbalanced supply. *(R.G.P.V., Dec. 2012)*

Or

Define the three phase balanced supply. *(R.G.P.V., Dec. 2013)*

Ans. Refer the ans. of Q.50.

Q.52. Describe star connection method for interconnection of 3-phase supply. *(R.G.P.V., Dec. 2011)*

Or

Derive the relationship between a line current and a phase current related to a star connected and delta connected load. *(R.G.P.V., Dec. 2015)*

Ans. There are two general methods of interconnections of 3-phase system –

(i) Star or Wye (Y) connection

(ii) Mesh or Delta (Δ) connection.

(i) Star or Wye (Y) Connection – In star connection, the three phase conductors of same ends are joined together to form a neutral point N. Such interconnection of 3-phase is called ***star connection*** and is represented by symbol Y. The junction of the three wires is normally called ***star or neutral point (N).***

If 3-phase voltage system is applied across a balanced symmetrical load, the neutral wire carrying three currents which are 120° apart in phase and equal in magnitude, thus, their vector sum would be zero, i.e.

$$I_N = I_R + I_Y + I_B = 0$$

If i_R, i_Y and i_B are the instantaneous values of the currents in the three phases, then their sum will be equal to zero to satisfy the property of star connection.

$$i_R = I_{max} \sin \theta'$$
$$i_Y = I_{max} \sin(\theta' - 120°)$$
$$i_B = I_{max} \sin(\theta' - 240°)$$

then, $$i_R + i_Y + i_B = I_{max} [\sin \theta' + \sin(\theta' - 120°) + \sin(\theta' - 240°)]$$
$$= 0$$

The potential difference between any terminal and neutral point gives ***phase voltage*** whereas potential difference between two lines gives the ***line voltage.***

Fig. 2.50 diagrammatically shows the star connection.

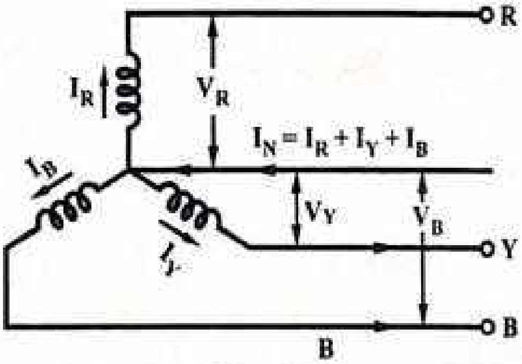


Fig. 2.50

(a) Line and Phase Currents – It is seen from the fig. 2.50 that each line is in series with its individual phase winding, hence the line current in each line is the same as the current in the phase winding to which the line is connected.

If currents in lines R, Y, B are I_R, I_Y, I_B respectively. Then,

$$I_{ph} = I_R = I_Y = I_B$$

(b) Line and Phase Voltages – Line voltage (V_L) is defined as potential difference between two lines i.e., between R, Y or Y, B or B, Y.

The potential difference between R and Y is $V_{RY} = V_R - V_Y$, where V_R, V_Y, V_B are the (V_{ph}) phase voltages.

The position of phase voltages is given in the phasor diagram shown fig. 2.51.

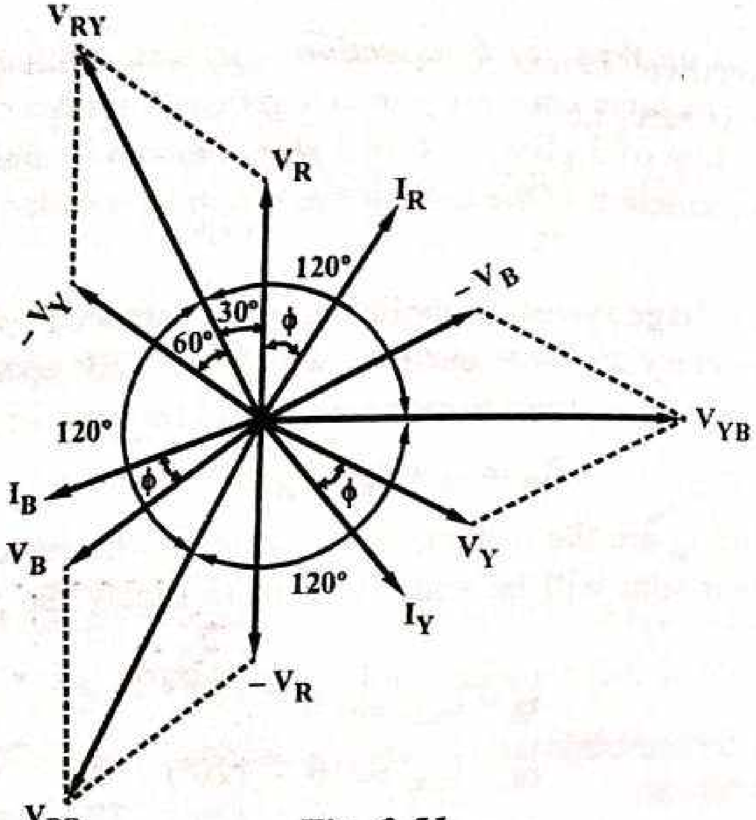


Fig. 2.51

V_{RY} is resultant of V_R and V_Y reversed and its value can be obtained a

$$V_{RY} = 2V_{ph} \times \cos\left(\frac{60°}{2}\right), \text{ because } V_R = V_Y = V_B = V_{ph}$$

or $$V_L = V_{RY} = 2\ V_{ph}.\cos 30° = 2\ V_{ph} \times \frac{\sqrt{3}}{2} = \sqrt{3}\ V_{ph}$$

Similarly, $V_L = V_{YB} = \sqrt{3}\ V_{ph}$ and $V_L = V_{BR} = \sqrt{3}V_{ph}$

(c) Power – The total active power or true power in the circuit is the sum of the three phase powers.

Hence, total active power = 3 × Phase power

or $$P = 3 \times V_{ph}I_{ph} \cos \phi$$

Now, $V_{ph} = V_L/\sqrt{3}$ and $I_{ph} = I_L$.

Hence, in terms of line values, the above expression becomes,

$$P = 3 \times \frac{V_L}{\sqrt{3}} \times I_L \times \cos\phi = \sqrt{3}V_L I_L \cos\phi$$

It should be noted that ϕ is the angle between phase voltage and phase current and not between the line voltage and line current.

(ii) Delta (Δ) or Mesh Connection – In delta connection, the three isolated phases are connected to form a closed delta or mesh, starting end of

one phase being joined to the finishing end of another phase. This type of connection of 3-phases of the system is called ***delta or mesh*** and is represented by the symbol, Δ.

For a symmetrical, balanced circuit, the sum of the three voltages round the closed mesh is zero, i.e.

$$V_R = V_{max} \sin \theta$$

$$V_Y = V_{max} \sin(\theta - 120^\circ)$$

and

$$V_B = V_{max} \sin(\theta - 240^\circ)$$

Then, $V_R + V_Y + V_B = V_{max} [\sin \theta + \sin(\theta - 120^\circ) + \sin(\theta - 240^\circ)]$

$$= 0$$

(a) Line and Phase Currents – It is seen from the fig. 2.52 that current in each line is the vector difference of the two phase currents flowing through that line.

∴ Current in line 1 is $I_1 = I_R - I_B$

Current in line 2 is $I_2 = I_Y - I_R$

Current in line 3 is $I_3 = I_B - I_Y$

and the value of these currents can be found by compounding of their respective currents.

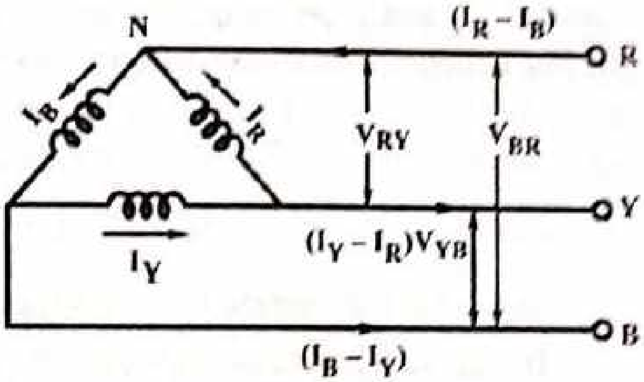


Fig. 2.52

From the fig. 2.53, current in line 1 can be calculated by compounding of I_R and I_B and value is given by resultant of both currents.

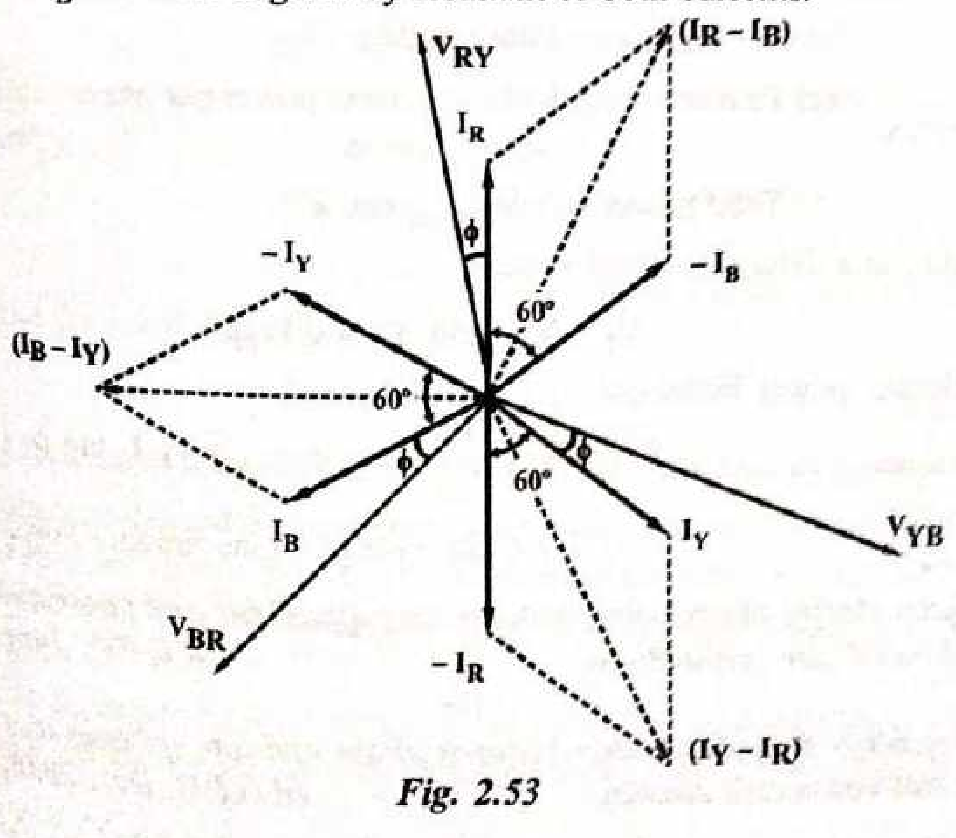


Fig. 2.53

The angle between I_R and I_B reversed is 60°. If $I_R = I_Y$ = Phase current I_{ph}, then

Current in line 1 is, $I_1 = 2 \times I_{ph} \times \cos (60°/2)$

$$= 2 \times I_{ph} \times \frac{\sqrt{3}}{2} = \sqrt{3}\, I_{ph}$$

Current in line 2 is, $I_2 = I_Y - I_R = \sqrt{3}\, I_{ph}$

Current in line 3 is, $I_3 = I_B - I_Y = \sqrt{3}\, I_{ph}$

Since all the line currents are equal in magnitude i.e.,

$I_1 = I_2 = I_3 = I_L = \sqrt{3}\, I_{ph}$, which are 120° apart from each other.

(b) Line and Phase Voltages – In Δ connection, the phase current I_1, I_2 and I_3 are equal in magnitude and displaced by 120°. Currents in the line conductors are now different than the phase currents. Let the currents in the three line conductors be I_R, I_Y and I_B. In the circuit, line current I_R is equal to the phasor difference of the phase currents I_1 and I_3, i.e.,

Line current $\quad I_R = I_1 - I_3 = 2\, I_{ph} \cos 30° = \sqrt{3}\, I_{ph}$

Similarly, line current $I_Y = \sqrt{3}\, I_{ph}$, $I_B = \sqrt{3}\, I_{ph}$

Hence, in a balanced 3-phase delta connected system,

Line current, $\quad I_L = \sqrt{3}\, I_{ph}$

Referring to fig. 2.52, it is obvious that the line voltages are equal to the phase voltages in a delta connected system.

Line voltage, V_L = Phase voltage, V_{ph}.

(c) Power – In a 3-phase system power per phase

$$= V_{ph}\, I_{ph} \cos \phi\ .$$

Total power $= 3\, V_{ph}\, I_{ph} \cos \phi$

But, in a delta connected system,

$$V_L = V_{ph} \text{ and } I_L = \sqrt{3}\, I_{ph}$$

Hence, power becomes

$$P = 3V_L \times \frac{I_L}{\sqrt{3}} \times \cos \phi = \sqrt{3}\, V_L\, I_L \cos \phi$$

$$= \sqrt{3} \times \text{Line voltage} \times \text{Line current} \times \text{Power factor.}$$

Q.53. Derive the relation between line quantities and phase quantities for balanced star connections. ***(R.G.P.V., June 2016)***

Or

Establish the relationship between phase and line voltages in a three-phase star connected circuit. ***(R.G.P.V., Dec. 2010, 2016)***

Or

Establish relationship between line and phase voltages and current in balanced star connected load. Draw complete phasor diagram of voltages and currents. ***(R.G.P.V., June 2017)***

Ans. Refer the ans. of Q.52 (i).

Q.54. Derive the expression for the active power and reactive power consumed by a balanced three phase delta connected load in terms of line voltage, line current and power factor. ***(R.G.P.V., Feb. 2005)***

Ans. The power per phase in delta connected for balanced three phase system is given by

$$P = V_{ph} I_{ph} \cos\phi$$

and, $$\text{Total power} = 3 V_{ph} I_{ph} \cos\phi \qquad ...(i)$$

We know that, in a delta connection,

$$\text{Phase voltage} = \text{Line voltage}$$

$$\therefore \quad V_{ph} = V_L$$

And line current is three times to the phase current i.e.,

$$I_{ph} = \frac{I_L}{\sqrt{3}}$$

By putting the values of I_{ph} and V_{ph} in the equation (i), we get

Total power, $$P = 3V_L \left(\frac{I_L}{\sqrt{3}}\right) \cos\phi$$

$$= \sqrt{3} V_L I_L \cos\phi \text{ watts}$$

$$= \sqrt{3} V_L I_L \cos\phi \times 10^{-3} \text{ kW}$$

Similarly the total reactive power in three phase balanced delta connection is given by

$$Q = \sqrt{3} V_L I_L \sin\phi \text{ VAR}$$

$$= \sqrt{3} V_L I_L \sin\phi \times 10^{-3} \text{ kVAR}$$

And the active power is given by

$$P = \sqrt{3} V_L I_L \cos\phi \times 10^{-3} \text{ kW}$$

Q.55. Discuss the unbalanced Δ and Y connected load in 3-phase system.

Ans. **Unbalanced Δ-connected Load** – When an unbalanced Δ-connected load is supplied from a balanced three-phase supply, the voltage across each load will remain fixed. It is independent of the nature of the load and is equal to line voltage.

The different phase currents can be calculated in the usual manner and the three line current can be obtained by solving these phase currents.

Unbalanced Y-connected Load – There are two cases to consider, when unbalance load connected in Y

(i) Unbalanced Y-connected load with neutral

(ii) Unbalanced Y-connected load without neutral.

(i) Unbalanced Y-connected Load with Neutral – In this case, unbalanced load may be treated as three separate single-phase system with a common return wire. It will be assumed that line wire and source phase windings are lossless. Under these assumption, source and load line terminals are at the same potential. There are two cases to consider

(a) Neutral wire with zero impedance

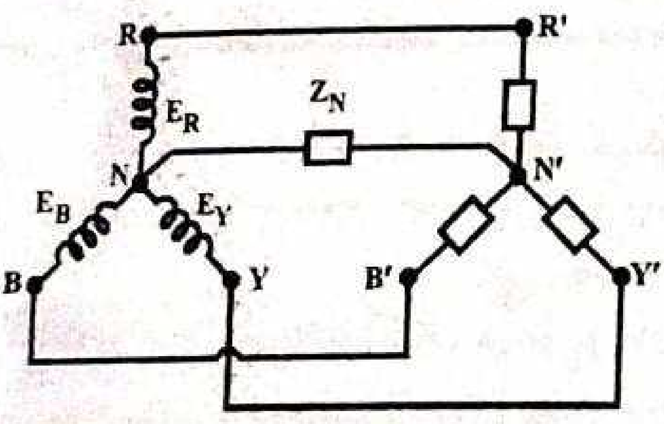
(b) Neutral wire of impedance Z_N.

(a) Neutral Wire with Zero Impedance – Due to the presence of neutral wire with zero impedance, the star point of the generator and load are tied together at the same potential. Hence, the voltage across each load equilized, which is equal to the voltage of the corresponding phase of the generator.

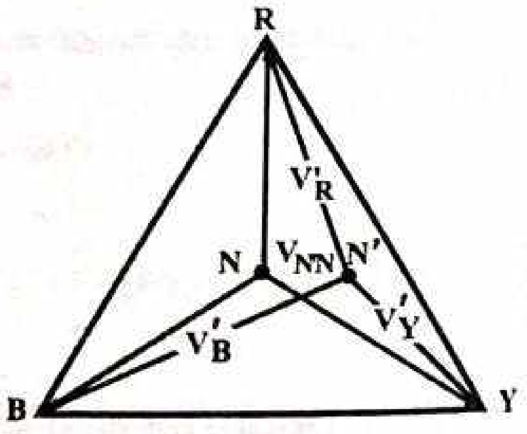
Four wire system with unbalanced load always causes large changes in current and voltage, thus no fuses and circuit breakers are ever used in this system.

Neutral current is equal to vector sum of currents in three lines.

(b) Neutral Wire of Impedance Z_N – Consider a case of a Y-to-Y system with a neutral wire of impedance Z_N as shown in fig. 2.54 (a). Let us assume that the impedance of line wires and source phase winding would be zero so that the line and load terminal R, Y, B and R', Y', B' are at the same respective potentials.



(a)



(b)

Fig. 2.54

According to Millman's theorem, the potential difference between supply and load neutral is given by

$$V_{N'N} = \frac{E_R Y_R + E_Y Y_Y + E_B Y_B}{Y_R + Y_Y + Y_B + Y_N}$$

where, Y_R, Y_Y, Y_B represents the load phase admittances, load neutral does not coincide with source neutral N. Hence load phase voltages are not equal to each other as shown in fig. 2.54 (b).

The load phase voltage are given by,

$$V'_R = E_R - V_{N'N}\ ;\ V'_Y = E_Y - V_{N'N} \text{ and } V'_B = E_B - V_{N'N}$$

The phase currents are,

$$I_R = V'_R Y_R,\ I_Y = V'_Y Y_Y \text{ and } I_B = V'_B Y_B$$

The current in the neutral wire is $I_N = V_N Y_N$.

(ii) Unbalanced Y-connected Load without Neutral – In this case, star point of unbalanced load is isolated from star point of the generator. Generator's star point potential is subjected to variation due to unbalance loading conditions. Such an isolated neutral point is called a ***'floating' neutral point*** because its potential is always changing and is not fixed.

Any unbalancing of load cause variations in the potential of star point and voltage across different branches of the load. Hence, in case of unbalanced Y-connected load without neutral phase voltage of the load is not $1/\sqrt{3}$ of the line voltage.

Following methods are used to solve problem of such unbalanced Y-connected loads having isolated neutral points –

(a) By converting the Y-connected load to an equivalent Δ-connected load by using Y-Δ conversion theorem.

(b) By using Millman's theorem.

The voltage between common point of generator and floating neutral is given by

$$V_{n0'0} = \frac{V_{10}Y_1 + V_{20}Y_2 + V_{30}Y_3 + \ldots + V_{n0}Y_n}{Y_1 + Y_2 + Y_3 + \ldots + Y_n}$$

where Y_1, Y_2, Y_3........Y_n are admittances of unbalanced load connected to common point, the voltage of the free ends of these admittances with respect to another common point are V_{10}, V_{20},....V_{n0} and $V_{n0'0}$ is the voltage between both common points.

(c) By applying Kirchhoff's law – Let V_{ab}, V_{bc}, V_{ca} are line voltages and Z_a, Z_b, Z_c are the branch impedances, then currents flowing through line to neutral are –

$$I_{ao} = \frac{V_{ab}Z_c - V_{ca}Z_b}{Z_aZ_b + Z_bZ_c + Z_cZ_a},\ I_{bo} = \frac{V_{bc}Z_a - V_{ab}Z_c}{Z_aZ_b + Z_bZ_c + Z_cZ_a}$$

$$I_{co} = \frac{V_{ca}Z_b - V_{bc}Z_a}{Z_aZ_b + Z_bZ_c + Z_cZ_a}$$

Q.56. Explain the meaning of phase sequence and balanced and unbalanced supply and loads. *(R.G.P.V., Nov. 2018)*

Ans. Refer the ans. of Q.47, Q.50 and Q.55.

Q.57. Distinguish the 3-phase balanced and unbalanced supply with phasor diagram. *(R.G.P.V., June 2013)*

Or

Distinguish between 3 phase balanced and unbalanced supply. What is the impact of unbalanced load on the power supply ? *(R.G.P.V., June 2014)*

Ans. Refer the ans. of Q.50, Q.52 and Q.55.

NUMERICAL PROBLEMS

Prob.11. A balanced star connected load is supplied from a symmetrical 3-phase 400 volt (line to line) supply. The current in each phase is 50 amp and lags 30° behind phase voltage. Find –

(i) Phase voltage (ii) Phase impedance

(iii) Active and reactive power drawn by the load. Also draw the phasor diagram for the same. *(R.G.P.V., Dec. 2012)*

Sol. Given, line voltage = $V_L = 400$ V

Phase current = $I_{ph} = 50$ A.

Phase angle = $\phi = 30°$ (lagging)

(i) Phase voltage = $V_{ph} = \dfrac{V_L}{\sqrt{3}} = \dfrac{400}{\sqrt{3}} \simeq 231$ V **Ans.**

(ii) As the system is star-connected

$$I_{ph} = I_L = 50\angle{-30°}\ \text{A}.$$

$$Z_{ph} = \frac{231\angle 0°}{50\angle -30°}$$

$$= 4.62\angle 30°\ \Omega \quad \textbf{Ans.}$$

(iii) Active power

$$P = \sqrt{3}V_L I_L \cos\theta$$

$$= \sqrt{3} \times 400 \times 50 \cos 30°$$

$$= 30\ \text{kW}$$

Reactive power

$$Q = \sqrt{3}\, V_L I_L \sin\theta$$

$$= \sqrt{3} \times 400 \times 50 \sin 30°$$

$$= 17.32\ \text{kVAR}$$

The phasor diagram is drawn in fig. 2.55.

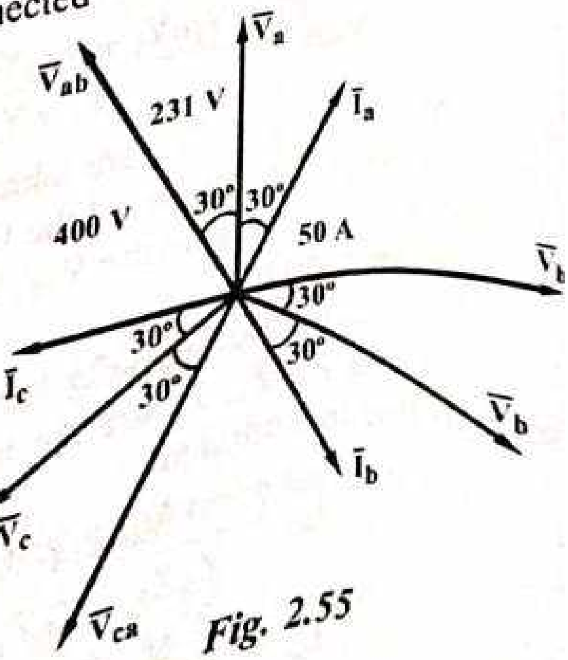


Fig. 2.55

Prob.12. A symmetrical 3-ϕ, 400 V system supplies a balanced load of 0.8 lagging power factor and connected in star. If the line current is 34.64 A, find –

(i) Impedance
(ii) Resistance and reactance per phase
(iii) Total power.

(R.G.P.V., Dec. 2015)

Sol. The voltage per phase is given by

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.94 \simeq 231\,V$$

$$I_L = I_{ph} = 34.64\ A$$

and
$$\cos\phi = 0.8\ \text{(lagging)}$$
$$\sin\phi = 0.6$$

(i) Impedance is given by,

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{231}{34.64} = \mathbf{6.67\ \Omega} \qquad \textbf{Ans.}$$

(ii) Resistance per phase is,

$$R_{ph} = Z_{ph}\cos\phi$$
$$= 6.67 \times 0.8 = \mathbf{5.34\ \Omega} \qquad \textbf{Ans.}$$

Reactance per phase is,

$$X_{ph} = Z_{ph}\sin\phi$$
$$= 6.67 \times 0.6$$
$$= \mathbf{4\ \Omega} \qquad \textbf{Ans.}$$

(iii) Total active power consumed is given by

$$= 3\,V_{ph}\,I_{ph}\cos\phi$$
$$= 3 \times 231 \times 34.64 \times 0.8$$
$$= 19204.42\ W$$
$$= \mathbf{19.2\ kW} \qquad \textbf{Ans.}$$

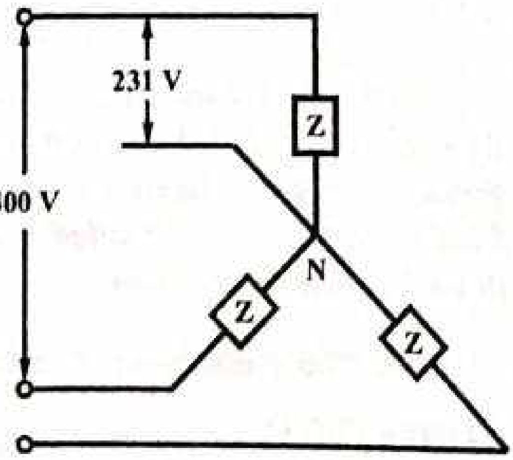


Fig. 2.56

The circuit diagram is shown in fig. 2.56.

Prob.13. A balanced star connected load of (8 + j6) ohms is connected across three-phase, 50 Hz, 440 V supply system. Calculate –

(i) Line current (ii) Power absorbed (iii) Reactive volt-ampere.

(R.G.P.V., Jan./Feb. 2008, Dec. 2017)

Sol. Fig. 2.57 shown the circuit diagram of having impedance (8 + j 6) Ω in each branch.

Impedance

$$Z_{ph} = \sqrt{8^2 + 6^2} = 10\ \Omega$$

and, voltage

$$V_{ph} = \frac{440}{\sqrt{3}} = 254\text{ V}$$

$$\therefore \quad I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{254}{10} = 25.4\text{ A}$$

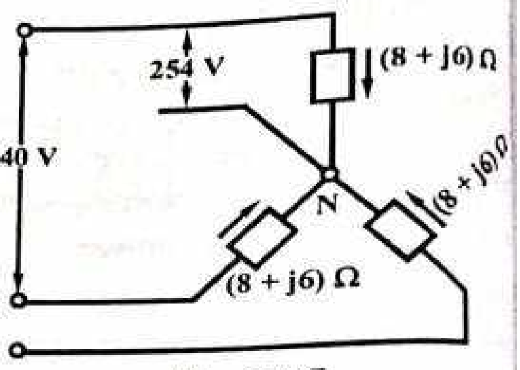


Fig. 2.57

Power factor is given by

$$\cos\phi = \frac{R_{ph}}{Z_{ph}} = \frac{8}{10} = 0.8 \text{ (lag)}$$

(i) In star connection, line current is equal to phase current, i.e.,

$$I_{ph} = I_l = \mathbf{25.4\ A}$$ **Ans.**

(ii) Power absorbed is total power which is given by

$$P = \sqrt{3}V_L I_L \cos\phi$$
$$= \sqrt{3} \times 440 \times 25.4 \times 0.8$$

or $$P = 15485.92\text{ W or } \mathbf{15.486\ kW}$$ **Ans.**

(iii) Reactive volt-ampere power is given

$$S = \sqrt{3}V_L I_L$$
$$= \sqrt{3} \times 440 \times 25.4\text{ W}$$
$$= 19357.39\text{ W or } \mathbf{19.357\ kW}$$ **Ans.**

Prob.14. A balanced delta-connected load having an impedance $Z_L = (300 + j210)\Omega$ in each phase is supplied from 400 V, 3-ϕ supply through a 3-ϕ line having an impedance of $Z_S = (4 + j8)\Omega$ in each phase. Find the total power supplied to the load as well as the current and voltage in each phase of the load. ***(R.G.P.V., June 2007)***

Sol. The equivalent Y-load of the given Δ-load is $= \dfrac{(300 + j210)}{3}$ $= (100 + j70)\ \Omega$

Hence, connections become as shown in fig. 2.58.

$$Z_{a'o} = (4 + j\,8) + (100 + j\,70)$$
$$= 104 + j\,78 = 130\ \angle 36.9^\circ$$

$$V_{a'o} = \frac{400}{\sqrt{3}} = 231\text{ V}$$

Let $V_{a'o} = 231\ \angle 0^\circ$

$$I_{a'o} = 231\ \angle 0^\circ / 130\ \angle 36.9^\circ$$
$$= 1.78\ \angle -36.9^\circ$$

Now $Z_{a'o} = (4 + j\,8) = 8.94\ \angle 63.4^\circ$

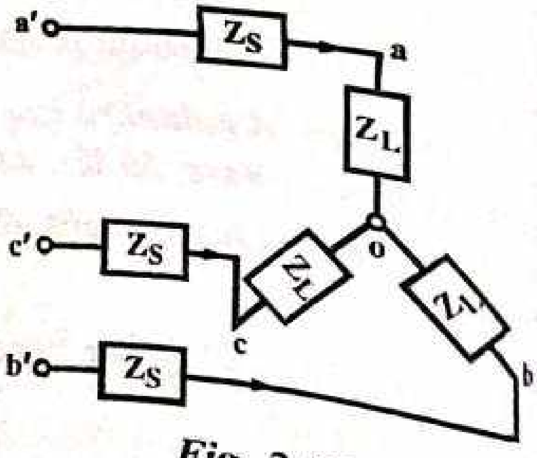


Fig. 2.58

Line drop

$$V_{a'a} = I_{a'a} \times Z_{a'a}$$
$$= 1.78 \angle -36.9° \times 8.94 \angle 63.4°$$
$$= 15.9 \angle 26.5° = 14.2 + j\,7.1$$

$$\therefore \quad V_{ao} = V_{a'o} - V_{a'a}$$
$$= (231 + j\,0) - (14.2 + j\,7.1)$$
$$= (216.8 - j\,7.1) = 216.9 \angle -1°52'$$

Phase voltage at load end,

V_{ao} = **216.9 V** **Ans.**

Phase current at load end,

I_{ao} = **1.78 A** **Ans.**

Power supplied to load = $3 \times (1.78)^2 \times 100$ = **950.52 W** **Ans.**

Incidentally, line voltage at load end, $V_{ac} = 216.9 \times \sqrt{3}$ = **375.7 V** **Ans.**

POWER IN BALANCED & UNBALANCED THREE-PHASE SYSTEM AND THEIR MEASUREMENTS

Q.58. How is the power measured in 3-phase circuit ?

(R.G.P.V., Dec. 2006, Nov./Dec. 2007)

Or

Explain all the methods of 3-phase power measurement in balanced 3-phase circuit. ***[R.G.P.V., June 2008 (O)]***

Ans. There are three methods used to measure power in a 3-phase load –

(i) One wattmeter method

(ii) Two wattmeter method

(iii) Three wattmeter method.

(i) One Wattmeter Method – This method is used to measure power in the star connected balanced load with neutral point.

Power can be measured in this case by connecting a single wattmeter with its current coil in one line and pressure coil between line and the neutral as shown in fig. 2.59.

In the one wattmeter method, wattmeter reading gives the power per phase, then

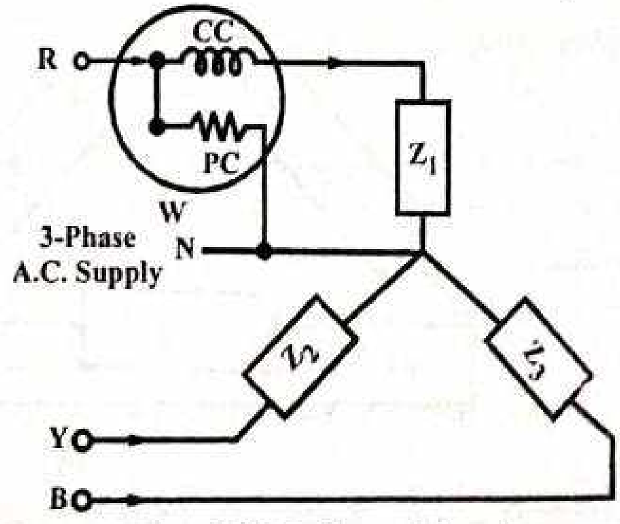


Fig. 2.59 Balanced Load

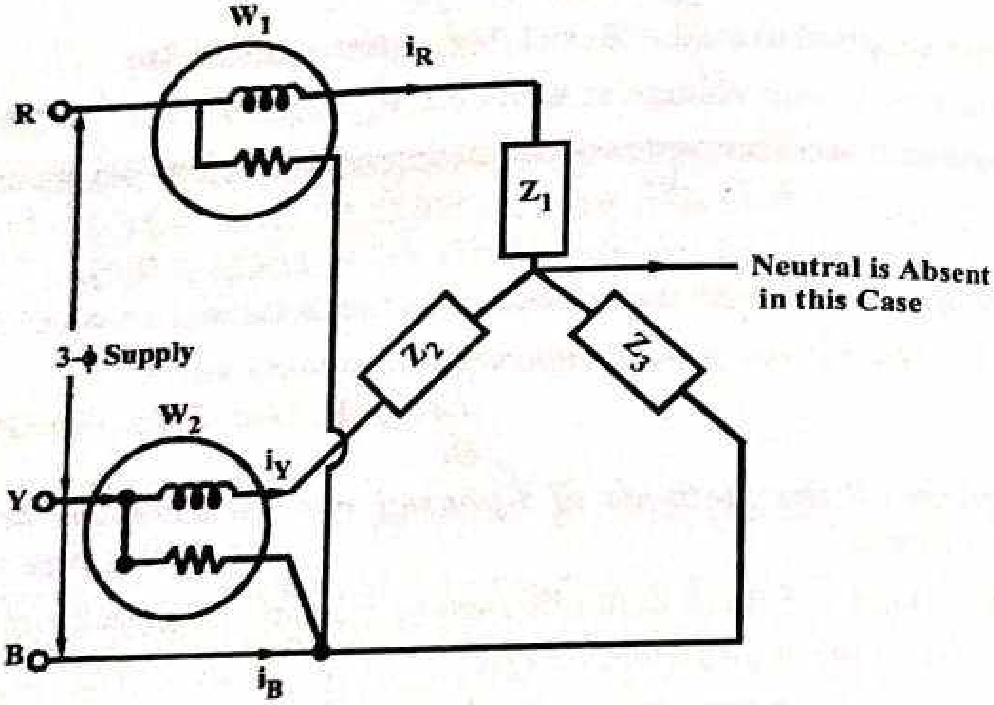
total power can be calculated as –

Total power = 3 × Wattmeter reading.

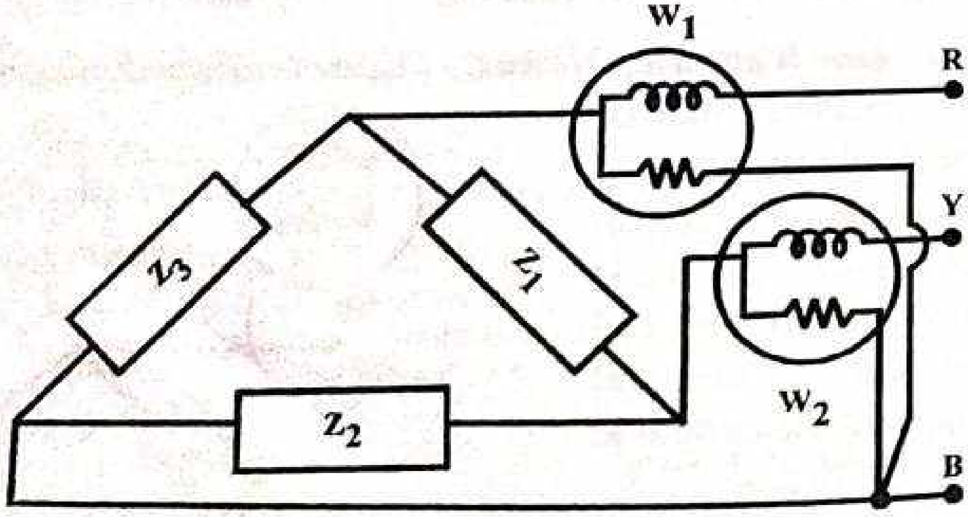
(ii) Two Wattmeter Method – This method is used extensively. Power in a three phase system, with balanced and unbalanced load can be measured by using two wattmeter method.

In this method current coil of wattmeter is supplied from current transformers inserted with main line wires in order to get correct magnitude and phase difference.

As shown in fig. 2.60 (a), the current coils of two wattmeter are inserted in any two lines and the pressure coils of each joined to the third line.



(a)



(b)

Fig. 2.60

Let e_R, e_Y, e_B be the voltages across the three phases of the load and i_R, i_Y and i_B are the current flowing in the three lines.

Direction of the voltage through the circuit should be same as that taken for the current when establishing the reading of the two wattmeters.

Instantaneous current through current coil of wattmeter 1,

$$W_1 = i_R$$

Potential difference across wattmeter 1,

$$W_1 = e_{RB} = e_R - e_B$$

Instantaneous current through current coil of wattmeter 2,

$$W_2 = i_Y$$

Potential difference across wattmeter 2,

$$W_2 = e_{YB} = e_Y - e_B$$

Instantaneous powers read by W_1 and W_2 are

$$W_1 = i_R (e_R - e_B)$$

$$W_2 = i_Y (e_Y - e_B)$$

$$\therefore \quad W_1 + W_2 = i_R (e_R - e_B) + i_Y (e_Y - e_B)$$

$$= i_R e_R + i_Y e_Y - e_B (i_R + i_Y)$$

Now $\quad i_R + i_Y + i_B = 0$

$$\therefore \quad i_R + i_Y = - i_B$$

or $\quad W_1 + W_2 = i_R.e_R + i_Y.e_Y + i_B.e_B$

$$= P_1 + P_2 + P_3$$

where, P_1, P_2 and P_3 are the powers consumed by impedances Z_1, Z_2, Z_3 respectively. Which is also equal to the true or active power of a 3-phase A.C. circuits.

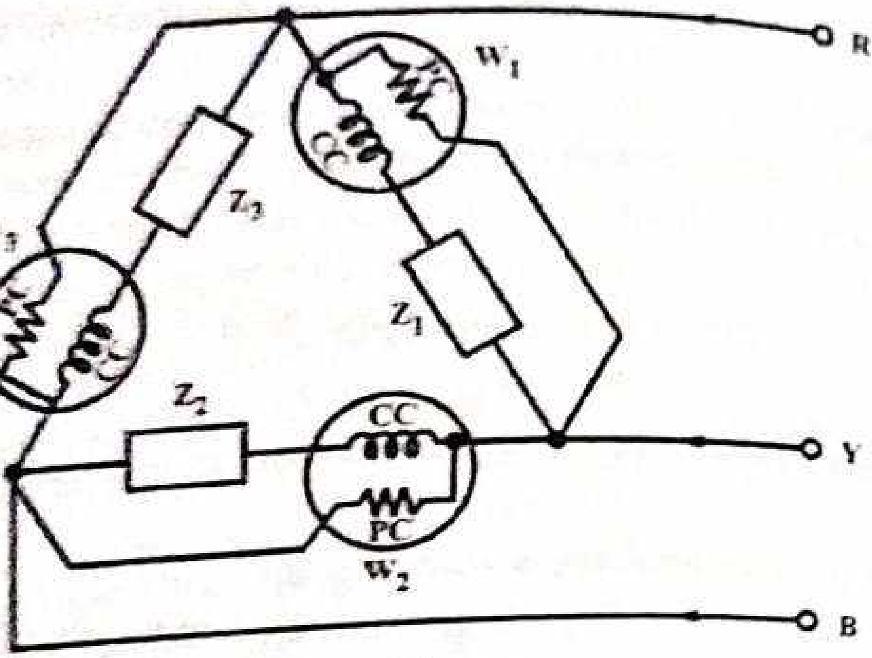
Hence at any instant, the total power is equal to the sum of the two wattmeter readings, and is the average power.

This proof is true for balanced and unbalanced loads but there should not be neutral connection in star-connected load.

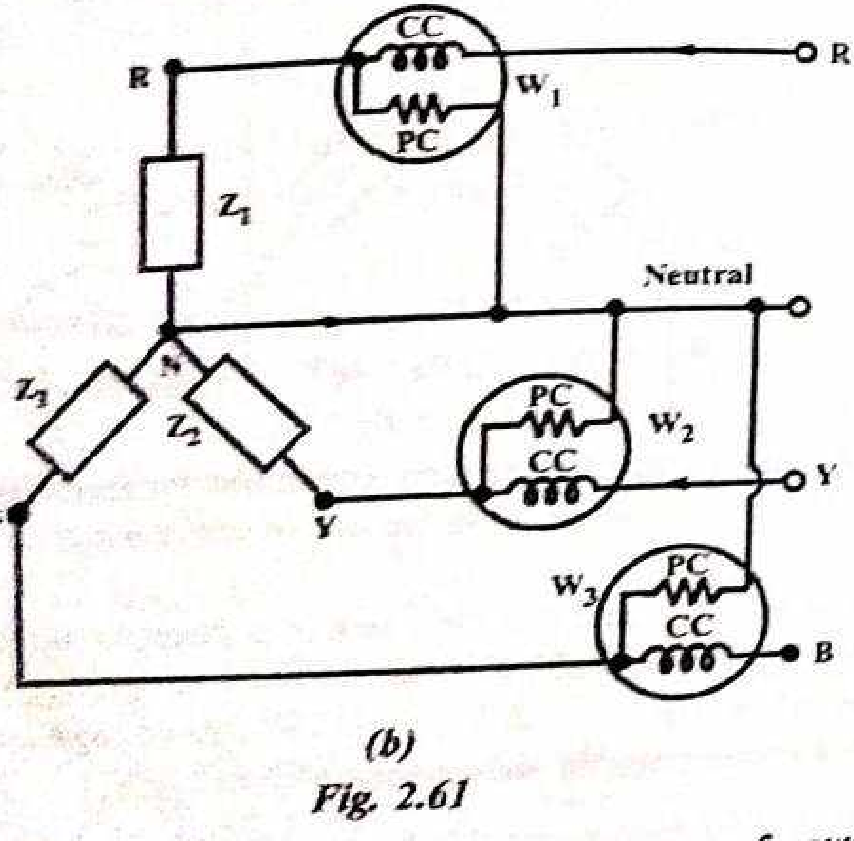
(iii) Three Wattmeter Method – A wattmeter consists of a current coil (CC) connected in series and a pressure coil (PC) of high resistance connected across the two points whose potential difference is to be measured.

As shown in fig. 2.61 (a) and (b), wattmeters are inserted in each of the three phases of load whether Δ-connected or Y-connected. The current coil of each wattmeter carries the current of single phase only and pressure coil gives the phase voltage of this phase.

Hence, each wattmeter measures single-phase power. The algebraic sum of the readings of three wattmeters give the total power consumed in load.



(a)



(b)

Fig. 2.61

Q.59. Derive an expression for the measurement of power factor i three phase system with balanced load using two wattmeter method.

Or

How you will measure power in three-phase A.C. circuit when balance load is connected across it ? ***(R.G.P.V., Jan./Feb. 2008, Dec. 201***

Ans. The star connected load in fig. 2.60 will be assumed inductive an balanced, then the power of the load can be found from two wattmeter metho Vector diagram for this balanced load is shown in fig. 2.62.

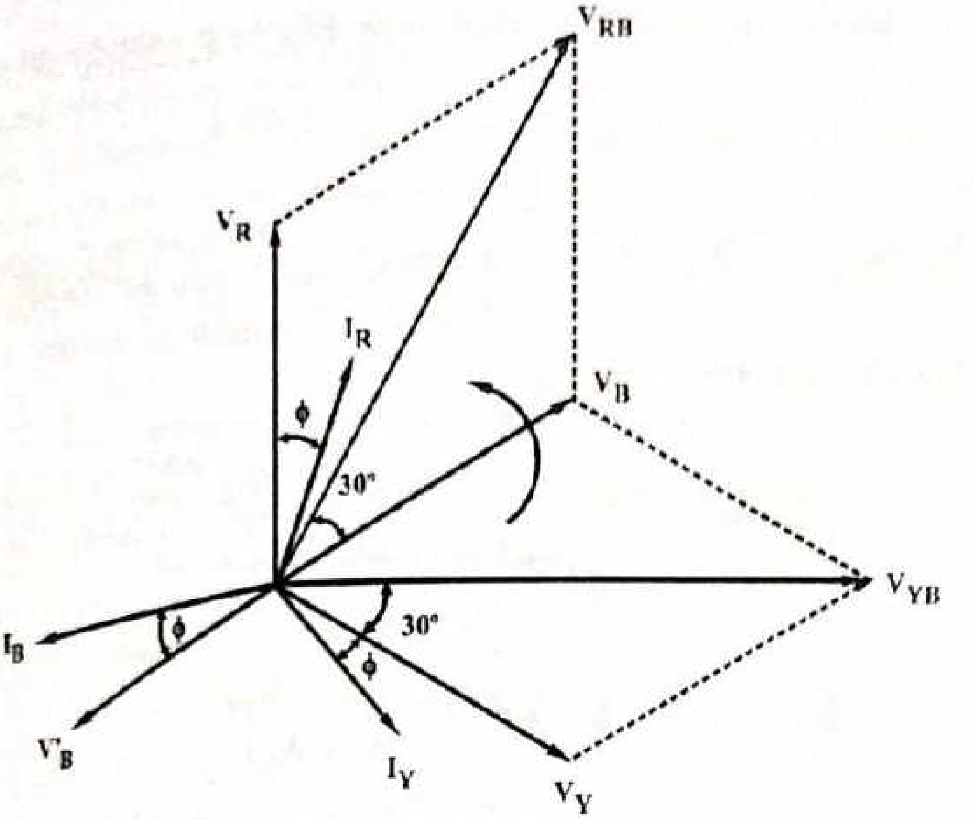


Fig. 2.62

Let V_R, V_Y and V_B be the r.m.s. phase values of the voltages and I_R, I_Y and I_B the r.m.s. values of the currents.

Due to the inductive load, currents lagging behind the respective phase voltages by ϕ.

Current through the coil of wattmeter,

$$W_1 = I_R$$

Potential difference across pressure coil of W_1,

$$V_{RB} = V_R - V_B$$

It is seen that the phase difference between V_{RB} and $I_R = 30° - \phi$

$\therefore$ Reading of $W_1 = I_R V_{RB} \cos(30° - \phi)$

Similarly,

Potential difference across,

$$W_2 = V_{YB} = V_Y - V_B$$

and current through $W_2 = I_Y$.

The angle between I_Y and V_{YB} is $(30° + \phi)$ as shown in fig. 2.62. Reading of $W_2 = I_Y V_{YB} \cos(30° + \phi)$

Since load is balanced,

$\therefore$ $$V_{RB} = V_{YB} = V_L$$

and $$I_Y = I_R = \text{Line current, } I_L$$

$\therefore$ $$W_1 + W_2 = V_L I_L \cos(30° - \phi) + V_L I_L \cos(30° + \phi)$$

$$V_LI_L[\cos 30° \cos\phi + \sin 30 \sin\phi + \cos 30° \cos\phi - \sin 30° \sin\phi]$$

$$= V_LI_L\, 2 \times \frac{\sqrt{3}}{2} \times \cos\phi$$

$$= \sqrt{3}\, V_L\, I_L \cos\phi \quad ...(i)$$

Similarly, $W_1 - W_2 = V_L\, I_L \cos(30° - \phi) - V_L\, I_L \cos(30° + \phi)$

$$= V_L\, I_L \sin\phi \quad ...(ii)$$

Dividing equation (ii) by (i), we have

$$\frac{V_LI_L \sin\phi}{\sqrt{3}V_LI_L\cos\phi} = \frac{(W_1 - W_2)}{(W_1 + W_2)}$$

$$\tan\phi = \frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}$$

$$\therefore \quad \phi = \tan^{-1}\left\{\frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right\}$$

and,
$$\cos\phi = \cos\left[\tan^{-1}\left\{\frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right\}\right]$$

For leading power factor

$$\tan\phi = \frac{-\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}$$

and for lagging power factor,

$$\cos\phi = \cos\left[\tan^{-1}\left\{\frac{-\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right\}\right]$$

Q.60. Specify the necessary condition for a given three-phase balanced system. How will you measure the power in balanced three-phase circuit? ***(R.G.P.V., June 2017)***

Ans. Refer the ans. of Q.49 and Q.59.

Q.61. Explain measurement of power and power factor in three phase system with balanced load by using two wattmeter method. ***(R.G.P.V., Dec. 2016)***

Ans. Refer the ans. of Q.58 (ii) and Q.59.

Q.62. Explain how power is measured using two wattmeter. ***[R.G.P.V., Nov. 2018(O)]***

Ans. Refer the ans. of Q.58 (ii).

Q.63. Determine the power in balanced and unbalanced three phase system and their measurements. ***(R.G.P.V., Nov. 2018)***

Ans. Refer the ans. of Q.58 and Q.59.

Q.64. With the help of a neat circuit diagram explain how 3-phase, power and power factor is determined in laboratory. (R.G.P.V., Sept. 2009)

Ans. In laboratory, two wattmeter method can be employed to determine 3-phase power and power factor. In this method, the current coils of the wattmeters are connected in any two lines say R and Y and the potential coil of each wattmeter is joined across the same line and the third line i.e, B. Fig. 2.63 shows a neat circuit diagram.

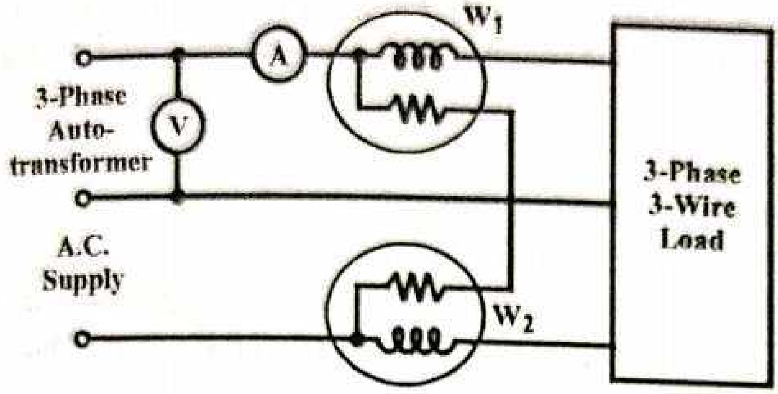


Fig. 2.63

Procedure – (i) Connect the voltmeter, ammeter and wattmeters to the load through 3-phase autotransformer as shown in fig. 2.63 and set-up the autotransformer to zero position.

(ii) Switch on the 3-phase A.C. supply and adjust the autotransformer till a suitable voltage. Note down the readings of wattmeters, voltmeter and ammeter.

(iii) Vary the voltage by autotransformer and note down the various readings.

Observations –

S. No.	*Voltmeter Readings (Volts)*	*Ammeter Readings (Amp)*	*Wattmeter Readings*		*Total Power* $P = W_1 + W_2$	*Power Factor* $\cos\phi = \frac{W_1 + W_2}{\sqrt{3}\, V_L I_L}$
			W_1	W_2		
(i)						
(ii)						
(iii)						
(iv)						
(v)						

Calculation – To calculate 3-phase power and power factor, we use following formulae.

Total power = $(W_1 + W_2) \times$ Multiplying factor

$$\tan\phi = \sqrt{3}\frac{W_2 - W_1}{W_1 + W_2}$$

and Power factor = $\cos\phi$

NUMERICAL PROBLEMS

Prob.15. ***A star-connected, balanced 3-phase circuit containing $Z = 20 \angle 30^\circ\ \Omega$ in each branch is connected across 400 V, 3-phase, 50 Hz 4 wire supply.***

Calculate –

(i) Current flowing through each branch

(ii) Total power drawn

(iii) Reading of two wattmeter connected for measurement of the total power. ***(R.G.P.V., Dec. 2002, June 2009)***

Sol. Given that,

$$Z_{ph} = 20 \angle 30^\circ\ \Omega$$

and $V_L = 400$ V

For star connection,

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231\ \text{V}$$

$$\therefore \quad I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{231}{20\angle 30^\circ} = 11.55\angle -30^\circ\ \text{A}$$

(i) Current flowing through each line

We know in star-connection,

$I_{ph} = I_L$ and each phase have 120° phase difference

$\therefore$ $I_A = 11.5 \angle -30^\circ$ A **Ans.**

$I_B = 11.5 \angle -150^\circ$ A **Ans.**

and, $I_C = 11.5 \angle -270^\circ$ A **Ans.**

where I_A, I_B and I_C are line currents.

(ii) Total power drawn

Total power drawn in 3-phase circuit is given by

$$P = 3\, V_{ph}\, I_{ph} \cos\phi$$

or

$$= \sqrt{3}.V_L I_L \cos\phi$$

$$= 3 \times 231 \times 11.55 \times \cos 30^\circ$$

$$P = 6.93\ \text{kW}$$

Ans.

(iii) Reading of two wattmeter connected for measurement of the total power

As shown in fig. 2.64 (a) reading of wattmeter W_1 is,

$= V_{AC} I_A \cos\phi$, phasor diagram for this system shown in fig. 2.64 (b).

I_A, I_B, I_C lags behind – 30°, – 150°, – 270° to reference phasor V_A, V_{AC} is the resultant phasor of V_A and $-V_C$, which is also 30° lags to reference phasor V_A.

$\because$ V_{AC} and I_A have not any phasor difference.

Hence,
$$W_1 = V_{AC} I_A \cos\phi$$
$$= 400 \times 11.55 \times \cos 0°$$
$$= \mathbf{4620\ W}$$ **Ans.**

And reading of wattmeter W_2 is,
$$= V_{BC} I_B \cos\phi$$

where, V_{BC} is the resultant of reversed V_C and V_B, which is at – 90° from reference phasor, whereas I_B at – 150° from reference phasor,

Hence for,
$$W_2 = 400 \times 11.55 \times \cos 60°$$
$$= \mathbf{2310\ W}$$ **Ans.**

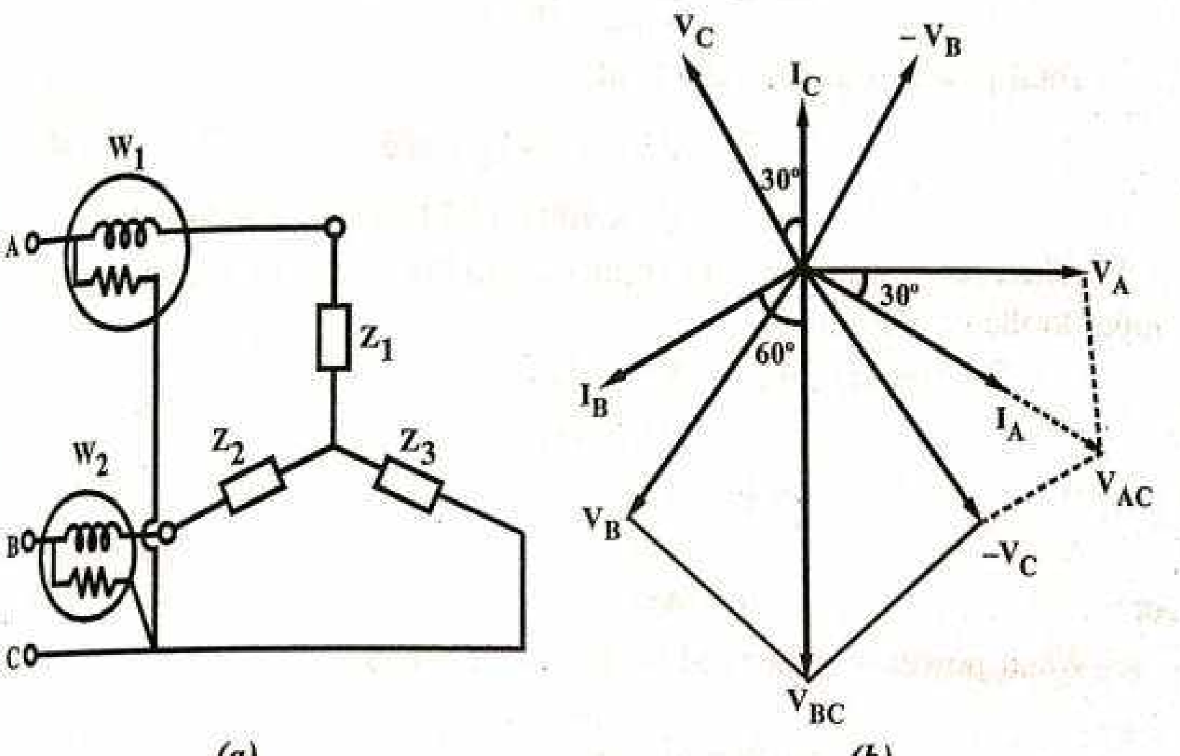


Fig. 2.64

Prob.16. Three choke coils each with a resistance of 10 ohm and reactance of 10 ohm are connected in star across a three-phase, 50 Hz, 400 volt supply. Calculate line current and reading of two wattmeters connected to measure the power. What is the total power drawn by the load. ***(R.G.P.V., Dec. 2005)***

Sol. Given,

Resistance, $R = 10$ ohm

Reactance, $X_L = 10$ ohm

and $V_L = 400$ volt

(Line voltage across the star-connected circuit)

$$\text{Phase voltage, } V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 230.94 \simeq 231 \text{ V}$$

Impedance of each coil, i.e., of each phase,

$$Z_{ph} = \sqrt{(10)^2 + (10)^2}$$
$$= 10\sqrt{2} = 14.14 \text{ ohms}$$

$$\text{Phase current, } \quad I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{231}{14.14} = 16.34 \text{ A}$$

For star connection,

Line current I_L = Phase current I_{ph} = **16.34 A** Ans.

Power factor of the circuit is given by

$$\cos\phi = \frac{R_{ph}}{Z_{ph}} = \frac{10}{14.14} = 0.707$$

Total power drawn by the load

$$P = \sqrt{3} \times V_L \times I_L \cos\phi$$
$$= \sqrt{3} \times 400 \times 16.34 \times 0.707 = 8.004 \text{ kW}$$

When two wattmeters are connected in the circuit to measure the power input to the circuit, then

$$\text{Power input} = W_1 + W_2$$
$$= 8004 \text{ watt}$$

$\because$ $\cos\phi = 0.707$

$\therefore$ $\phi = \cos^{-1}(0.707)$

or $\phi = 45°$

When power is measured by two wattmeters

$$\tan\phi = \sqrt{3}\left[\frac{W_1 - W_2}{W_1 + W_2}\right]$$

$$\tan 45° = \sqrt{3}\left[\frac{W_1 - W_2}{W_1 + W_2}\right]$$

$$W_1 - W_2 = \frac{8004}{\sqrt{3}} = 4621 \text{ watts}$$

By solving we get,

$$W_1 = \mathbf{6312.5\ watts} \text{ and } W_2 = \mathbf{1691.5\ watts} \qquad \textbf{Ans.}$$

Total power drawn by the load is

$$= W_1 + W_2$$
$$= 6312.5 + 1691.5$$
$$= \mathbf{8004\ watts} \qquad \textbf{Ans.}$$

Prob.17. A 3-phase, 400 V, 50 Hz induction motor has a full-load output of 14.9 kW at which the efficiency and power factor are 0.88 and 0.8 respectively. Find the readings on the two W.M. connected to measure the power input to the motor. What is the full-load current ? ***(R.G.P.V., Dec. 2008)***

Sol. Power output of 3-phase induction motor = 14.9 kW

Efficiency of the motor = 88%

$$\text{Power input to the motor} = \frac{\text{Output}}{\text{Efficiency}} = \frac{14.9}{0.88} = 16.93\ \text{kW}$$

Power input when measured by two wattmeter method = $W_1 + W_2$ where W_1 and W_2 are the readings of the two wattmeters.

Hence $\qquad W_1 + W_2 = 16.93 \qquad$ ...(i)

Given, power factor of the motor = 0.8

$$\cos\phi = 0.8$$
$$\phi = 36.87^\circ$$

In two wattmeter method,

$$\tan\phi = \sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$$

$$\tan 36.87 = \sqrt{3}\left(\frac{W_1 - W_2}{16.93}\right)$$

$$0.75 = 0.1023(W_1 - W_2)$$

or $\qquad W_1 - W_2 = 7.33 \qquad$ ...(ii)

After solving equations (i) and (ii), we have

$$W_1 = 12.13\ \text{kW},\ \ W_2 = 4.8\ \text{kW}$$

Hence, the readings of the two wattmeters are **12.13 kW and 4.8 kW.** **Ans.**

Full load line current drawn by the motor

$$= \frac{\text{Power input}}{\sqrt{3} \times V_L \times \cos\phi}$$

$$= \frac{16.93 \times 10^3}{\sqrt{3} \times 400 \times 0.8} = \mathbf{30.5\ amp.} \qquad \textbf{Ans.}$$

***Prob.18.** A three phase, 440 V motor load has a power factor of 0.6. Two wattmeters connected to measure the power show the input to be 25 kW. Find the reading on each instrument.* **(R.G.P.V., June 201[illegible])**

Sol. Given input power = 25 kW = 25000 W.

Line voltage = 440 V.

$\cos\phi = 0.6 \Rightarrow \phi = \cos^{-1}(0.6) = 53.13°$

We know that,

$$V_L I_L = \frac{P}{\sqrt{3}\cos\phi} = \frac{25000}{\sqrt{3} \times 0.6} = 24056 \text{ VA}$$

$$\text{Reading of wattmeter } W_1 = V_L I_L \cos(30° - \phi)$$

$$= 24056 \cos(30° - 53.13°)$$

$$= 22122 \text{ W} = \mathbf{22.122 \text{ kW}}$$ **Ans.**

$$\text{Reading of wattmeter } W_2 = V_L I_L \cos(30° + \phi)$$

$$= 24056 \cos(30° + 53.13°)$$

$$= 2877 \text{ W} = \mathbf{2.877 \text{ kW}}$$ **Ans.**

UNIT 3

MAGNETIC CIRCUITS AND SINGLE PHASE TRANSFORMER

MAGNETIC CIRCUITS – BASIC DEFINITIONS, MAGNETIZATION CHARACTERISTICS OF FERROMAGNETIC MATERIALS

Q.1. Define the following terms –

(i) Magnetic circuit

(ii) Magnetizing force *(R.G.P.V., Dec. 2001)*

(iii) Reluctance *(R.G.P.V., Sept. 2009)*

(iv) Permeance. *(R.G.P.V., Sept. 2009)*

Ans. ***(i) Magnetic Circuit*** – The closed path followed by magnetic flux is called a magnetic circuit. A magnetic circuit usually consists of magnetic materials having high permeability (e.g., iron, soft steel etc.). In this circuit, magnetic flux starts from a point and finishes at the same point after completing its path.

(ii) Magnetizing Force – Force experienced by a unit magnetic pole in magnetic field is called magnetizing force or field intensity.

$$\text{Magnetizing force or field intensity } H = \frac{m}{4\pi\mu_0 d^2} \text{ N/Wb or AT/m or oersted.}$$

where d is distance from the pole of m webers to point at which magnetizing force is measured.

(iii) Reluctance – The reluctance is the property of the magnetic material which opposes the flow of magnetic flux through it.

or

The reluctance of a magnetic circuit is the number of ampere-turns required per weber of magnetic flux in the circuit.

$$\text{Reluctance} = \frac{l}{\mu_0\mu_r A} \text{ AT/Wb or henry}^{-1} \qquad \text{(for magnetic materials)}$$

$$\text{and Reluctance} = \frac{l}{\mu_0 A} \text{ AT/Wb or henry}^{-1} \qquad \text{(for non-magnetic materials)}$$

where μ_r, μ_0 are the relative and absolute permeabilities, l and A are lengths of magnetic circuit and cross-sectional area of that circuit respectively.

(iv) Permeance – It is reciprocal of reluctance and analogous to conductance in electric circuits. It is measured in the terms of Wb/AT or henry.

$$\text{Permeance} = \frac{\mu_0 \mu_r A}{l}$$

Q.2. Define the following terms –

(i) Relative permeability ***(ii) Magnetic flux***
(iii) B-H curve ***(iv) Leakage coefficient***
(v) Magnetic field strength.

Ans. (i) Relative Permeability – Permeability of a medium with reference to vacuum of free space is called ***relative permeability***, vacuum have absolute permeability (μ_0) = $4\pi \times 10^{-7}$ henry/metre

$$\therefore \quad \text{Relative permeability} = \frac{\text{Absolute permeability of medium}}{\text{Permeability of vacuum}}$$

(ii) Magnetic Flux – A line of flux is a closed path around the current such that the magnetic force is tangential to it at all points around the line. The direction of flux is given by the right hand rule. It is denoted by ϕ and its unit is weber.

$$\phi = \frac{NI}{l/\mu_0 \mu_r A} \text{Wb}$$

(iii) B-H Curve – The graph plotted between flux density **B** and magnetizing force **H** of a material is called the magnetization or B-H curve of that material.

(iv) Leakage Coefficient – It is defined as the ratio of total flux to useful flux. It is also known as ***leakage factor*** i.e.,

$$\text{Leakage coefficient, } \lambda = \frac{\text{Total flux}}{\text{Useful flux}}$$

where Total flux = Leakage flux + Useful flux.

Leakage flux is the flux which follows a path not intended for it. In other words, it is the flux which is just set-up around the coil and is not utilized for any work. For electrical machines, the value of leakage factor varies between 1.1 to 1.25.

(v) Magnetic Field Strength – If the magnetic circuit of a magnetic material is homogeneous and of uniform cross-sectional area, the magnetomotive force per metre length of the magnetic circuit is called the magnetic field strength. It is represented by H. Hence, the magnetic field strength is

$$H = \frac{\text{M.M.F.}}{l} = \frac{NI}{l} \text{AT/m}$$

where, l is the length of the magnetic flux path in metre.

Q.3. Define magnetic leakage and fringing. ***(R.G.P.V., Dec. 2014)***

Ans. **Magnetic Leakage** – Magnetic leakage can be defined as the passage of magnetic flux outside the path along which it can do useful work.

Fringing – At an air-gap in a magnetic core, the flux fringes out into neighbouring air paths as shown in fig. 3.1 these being of reluctance comparable to that of the gap. The result is nonuniform flux density in the air-gap, enlargement of the effective air-gap area and a decrease in the average gap flux density. The fringing effect also disturbs the core flux pattern to some depth near the gap.

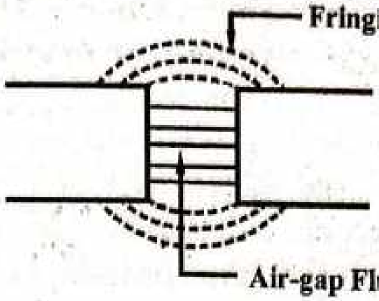


Fig. 3.1

The effect of fringing increases with the air-gap length.

Q.4. Define and give the ampere turns for a magnetic circuit.

Ans. The M.M.F. acting around a complete magnetic circuit is equal to the total ampere turns required to force the given flux through the magnetic circuit, thus,

$$\text{Total ampere turns} = \frac{B_1}{\mu_1}l_1 + \frac{B_2}{\mu_2}l_2 + \frac{B_3}{\mu_3}l_3 + \ldots\ldots \quad \ldots(i)$$

The ampere turn per unit length is calculated by the relation $AT = H \times l$, is then multiplied by the length of magnetic flux path, in order to get the total ampere turns.

The total ampere turns needed for the complete magnetic circuit is then found out by adding algebraically the ampere turns needed for the various parts of the magnetic circuit.

Q.5. Define the following terms –

(i) M.M.F. ***(R.G.P.V., Sept. 2009, Dec. 2011)***
(ii) Flux ***(iii) Permeability***
(iv) Magnetic field intensity ***(v) Susceptance***
(vi) Magnetic field density.

(R.G.P.V., June 2016)

Ans. (i) M.M.F. – It drives or tends to drive flux through a magnetic circuit and corresponds to electromotive force (e.m.f.) in an electric circuit.

M.M.F. can be produced when current flows in a coil of one or more turns. The magnitude of m.m.f. is directly proportional to the current I and the number of turns of the coil N.

$$\therefore \qquad \text{M.M.F.} = NI \text{ amp-turns}$$

(ii) Flux – Refer the ans. of Q.2 (ii).

(iii) Permeability – When a magnetic material placed in a magnetic field acquires magnetism due to induction. Measure of the degree to which the

lines of force of the magnetizing field can penetrate or permeate the medium known as absolute permeability of the medium. It is represented by a symbol
It is analogous to conductivity in electric circuits.

(iv) Magnetic Field Intensity – Refer the ans. of Q.2 (v).

(v) Susceptance – The susceptance is the imaginary part of admittance (Y), which is given by

$$Y = G + jB$$

(vi) Magnetic Field Density – The magnetic field density at a point is the flux per unit area at right angles to the flux at that point. It is denoted by B. Its unit is Wb/m^2 or tesla, i.e.

$$B = \frac{\phi}{A} \, Wb/m^2 \text{ or } T$$

where, ϕ = Total flux passing through that point
A = Cross-sectional area at that point.

Q.6. Do the comparison of electrical and magnetic circuit on the basis of similarities and dissimilarities.
(R.G.P.V., Jan./Feb. 2008, July 2008, Dec. 2017)

Or

Compare the electrical circuit with magnetic circuit. (R.G.P.V., June 2016)

Or

Compare magnetic circuit with electrical circuit in detail.
(R.G.P.V., Dec. 2016)

Or

Explain the similarities and dissimilarities between electric and magnetic circuit. (R.G.P.V., June 2017)

Or

Compare magnetic and electric circuits. [R.G.P.V., Nov. 2018(O)]

Or

Distinguish between electrical and magnetic circuits.
(R.G.P.V., May 2018)

Ans. **Analogy between Electric and Magnetic Circuits –**

Similarities		
S.No.	***Magnetic Circuit***	***Electric Circuit***
(i)	Flux is assumed to flow.	Current flows in the circuit.
(ii)	The path of flux is called magnetic circuit.	The path of current is called electric circuit.
(iii)	Flux flows due to m.m.f.	Current flows due to e.m.f.
(iv)	Flow of flux is restricted by reluctance of the circuit.	Flow of current is restricted by resistance of the circuit.

(v)	Flux $= \dfrac{\text{m.m.f.}}{\text{Reluctance}}$	Current $= \dfrac{\text{e.m.f.}}{\text{Resistance}}$
(vi)	Reluctance $= \dfrac{l}{\mu A}$	Resistance $= \rho \dfrac{l}{A}$
	Dissimilarities	
S.No.	***Magnetic Circuit***	***Electric Circuit***
(i)	Flux does not flow, actually it is assumed to flow for finding out certain magnetic effects.	Current actually flows in the circuit.
(ii)	Energy is needed only to create the magnetic flux.	Energy is needed till the current flows.
(iii)	Reluctance of the circuit changes with the magnetic flux.	Resistance of the circuit is independent of the current, if temperature is constant.

Q.7. What is
(i) Series and
(ii) Parallel magnetic circuit ?
(R.G.P.V., April 2009)

Ans. (i) Series Magnetic Circuit – A magnetic circuit that has a number of parts of different dimensions and materials carrying the same magnetic field is called a composite series magnetic circuit is shown in fig. 3.2.

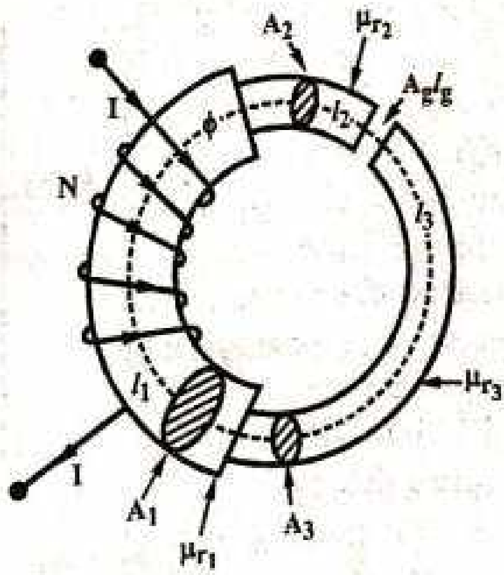


Fig. 3.2

Total reluctance of the magnetic circuit is given by

$$S = S_1 + S_2 + S_3 + S_g$$

$$= \frac{l_1}{A_1\mu_0\mu_{r_1}} + \frac{l_2}{A_2\mu_0\mu_{r_2}} + \frac{l_3}{A_3\mu_0\mu_{r_3}} + \frac{l_g}{A_g\mu_0}$$

Total M.M.F. $= \phi$ S

$$= \phi\left[\frac{l_1}{A_1\mu_0\mu_{r_1}} + \frac{l_2}{A_2\mu_0\mu_{r_2}} + \frac{l_3}{A_3\mu_0\mu_{r_3}} + \frac{l_g}{A_g\mu_0}\right]$$

$$= \frac{B_1 l_1}{\mu_0\mu_{r_1}} + \frac{B_2 l_2}{\mu_0\mu_{r_2}} + \frac{B_3 l_3}{\mu_0\mu_{r_3}} + \frac{B_g l_g}{\mu_0}$$

$$= H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g$$

Step by Step Calculation Procedure for Series Magnetic Circuits

(a) Divide the magnetic circuit into different parts.

(b) Determine the value of B (flux density) of different parts

$B = \frac{\phi}{A}$, where ϕ is the flux in Wb and A is the area of cross section in m^2.

(c) Calculate the value of H (magnetizing force) as

$H = \frac{B}{\mu_0 \mu_r}$, where $\mu_0 = 4\pi \times 10^{-7}$ and μ_r is given.

(d) After getting the values of H as H_1, H_2, H_3 or H_g, now individually it will be multiplied by the length of that part.

(e) Finally add all the $(H \times l)$.

So total m.m.f. $= \Sigma H \times l = H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g$

(ii) Parallel Magnetic Circuit – A magnetic circuit which has two or more than two paths for the magnetic flux is called a parallel magnetic circuit is shown in fig. 3.3. A current carrying coil is wound on the central limb AB. This coil sets-up a magnetic flux ϕ_1 in the central limb which is further divided into two paths i.e., (i) path ADCB which carries flux ϕ_2 and (ii) path AFEB which carries flux ϕ_3.

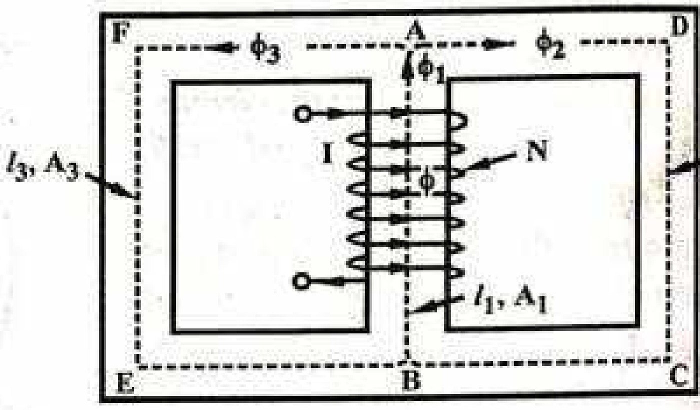


Fig. 3.3 Parallel Magnetic Circuit

It is seen that $\phi_1 = \phi_2 + \phi_3$

The two magnetic paths ADCB and AFEB are in parallel. The ATs required for this parallel circuit is equal to the ATs required for any one of the paths.

If S_1 = Reluctance of path BA i.e., $\frac{l_1}{A_1 \mu_0 \mu_{r_1}}$

S_2 = Reluctance of path ADCB i.e., $\frac{l_2}{A_2 \mu_0 \mu_{r_2}}$

S_3 = Reluctance of path AFEB i.e., $\frac{l_3}{A_3 \mu_0 \mu_{r_3}}$

Total m.m.f. required = m.m.f. required for path BA + m.m.f. required path ADCB or path AFEB i.e.,

Total M.M.F. or AT $= \phi_1 S_1 + \phi_2 S_2 = \phi_1 S_1 + \phi_3 S_3$

Q.8. Explain the procedure to analyse series magnetic circuit with air gap. ***(R.G.P.V., Dec. 2015)***

Ans. Refer the ans. of Q.7 (i).

Q.9. What is hysteresis loop ? Explain it by drawing hysteresis loop. ***(R.G.P.V., Dec. 2017)***

Ans. A typical property of ferromagnetic materials is hysteresis. Hysteresis may be defined as the lag in the changes of magnetization behind variations of the magnetic field. Because of hysteresis, the magnetization of a ferromagnetic material depends not only on the strength of the magnetizing field at the given instant but also on the magnetization history of the material.

If an initially unmagnetized specimen of a ferromagnetic material is subjected to increasing or decreasing magnetic fields, the magnetic field induction B varies as a function of H along a closed loop, called the ***hysteresis loop.*** The curve begins at the origin O. As H is increased, the field B begins to increase slowly, then more rapidly and finally attaining a saturation value and becoming independent of H. The maximum value of B is the saturation flux density B_s and the corresponding magnetization is saturation magnetization M_s. From saturation point A, the curve does not retrace its original path as the field H is reduced. At zero field point C, there exists a residual field which is called remanence or remanent flux density B_r. It indicates that the material remains magnetized even in the absence of an external applied field H.

To reduce magnetic induction within specimen to zero (point D), a field of magnitude $-H_c$ must be externally applied in a direction opposite to that of the original field. H_c is called the ***coercivity*** or the ***coercive force.***

As applied field is increased in negative direction, saturation is ultimately reached in the reverse direction (point E). On reversing the variation of the field H, a curve similar to ACDE is traced through points EFGA, yielding a negative remanence ($-B_r$) and a positive coercivity $+H_c$. This B-H curve is also known as hysteresis loop (refer fig. 3.4).

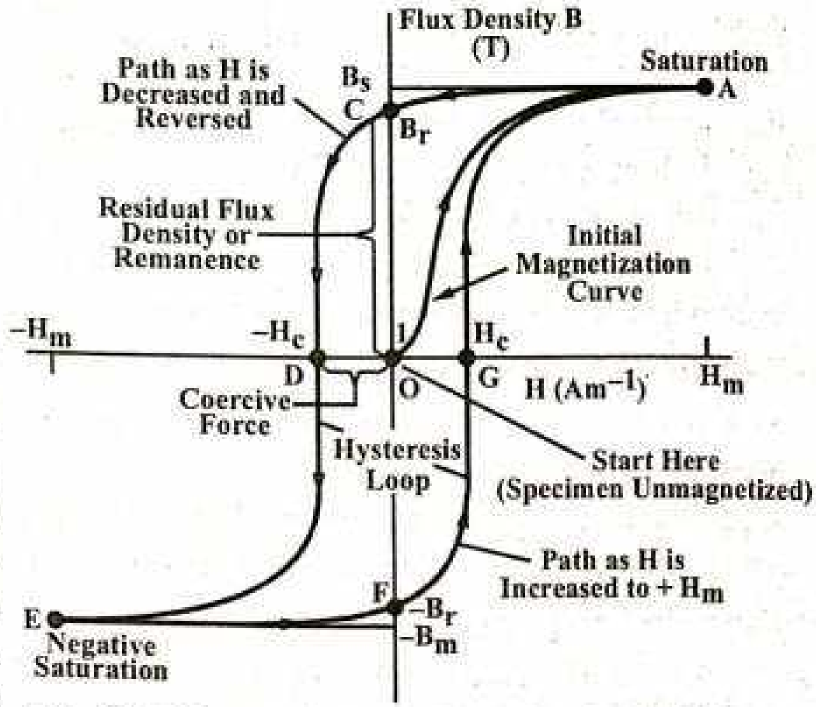


Fig. 3.4 Hysteresis Loop Showing Path of B as H is Changed

Q.10. Give the explanation of spontaneous magnetization ferromagnetic below the Curie temperature and Weiss-Curie law above Curie temperature.

Or

Discuss in brief the properties of ferromagnetic materials above and below the ferromagnetic Curie temperature.

Ans. The properties of ferromagnetic materials are quite different at above and below the Curie temperature. Below the Curie temperature, the ferromagnetic materials show spontaneous magnetization and above this temperature they follow the Curie Weiss Law. Here, we shall discuss the atomic interpretation of spontaneous magnetization and of the Curie Weiss Law.

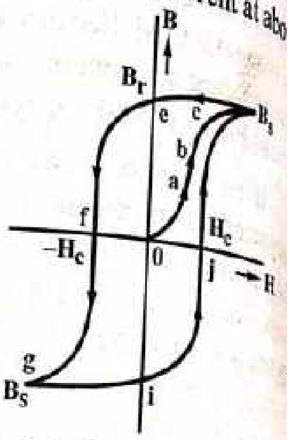


Fig. 3.5 Hysteresis Loop for a Ferromagnetic Specimen

The remanent flux density $\mathbf{B_r}$ of a typical ferromagnetic material used for permanent magnet is about 1 weber/m^2. Since $\mathbf{H} = 0$ at this point on the hysteresis loop as shown in fig. 3.5. Using equation $\mathbf{B} = \mu_0\mathbf{H} + \mu_0\mathbf{M}$.

$$\mathbf{M_r} = \frac{\mathbf{B_r}}{\mu_0} \approx 10^6 \text{ A/m, where } \mathbf{M_r} \text{ is the spontaneous magnetization.}$$

If each atom in the material has a magnetic moment of the order of one Bohr magneton, then the atomic density is $N = \frac{\mathbf{M_r}}{p_B} \approx 10^{29}$ atoms/m^3. Because the number of atoms in a solid is approximately 10^{29} per m^3, it is clear, that such a high remanent flux density can be explained only be assuming a spontaneous magnetization in which all the atoms of the material are so oriented that their magnetic moments are parallel. From this example, we can say that even when $\mathbf{H} = 0$, there exists some force of field in a ferromagnetic material which tends to magnetic dipole moments in parallel.

In 1907, Weiss pointed out that this behaviour could be understood by postulating that the elementary moments did interact with one another. He suggested that, interaction could be expressed in terms of fictitious internal field which he called the ***molecular field***, $\mathbf{H_m}$ and which acted in addition to the applied field $\mathbf{H}$.

Assumed that the intensity of the molecular field was directly proportional to the magnetization therefore

$$\mathbf{H_m} = \gamma\mathbf{M} \quad ...(i)$$

where, γ is called the molecular field constant. Thus the total internal field which acts in the material is

$$H_i = H + H_m$$

$$H_i = H + \gamma M \qquad ...(ii)$$

γ is also referred as internal field constant and it determines the strength of the interaction between the magnetic dipole moments in a material.

Now we shall do the analysis of ferromagnetic materials, assuming the internal field as given by (ii).

(i) Ferromagnetic Materials at High Temperature ($T > T_c$) – Even in case of ferromagnetic materials at very high temperature ($T > T_c$), the thermal agitation is so great that internal field is not sufficient to maintain alignment of magnetic dipole moments. The behaviour becomes similar to a paramagnetic material except that the field acting on the dipole is the internal field given by equation (ii).

As a model, let us consider a system of N spins per m^3, each giving rise to a magnetic moment of 1 Bohr magneton, $\mathbf{p}_B$, either parallel or antiparallel to the external field. The magnetization of such a system may be obtained for a paramagnetic case, which is given below –

$$\mathbf{M} = N\mathbf{p}_B \tanh\left[\frac{\mu_0 \mathbf{p}_B}{kT}(\mathbf{H} + \gamma\mathbf{M})\right] \qquad ...(iii)$$

At high temperatures, $\mu_0 \mathbf{p}_B (\mathbf{H} + \gamma\mathbf{M}) << kT$. Then since, $\tanh \alpha \cong \alpha$ for $\alpha << 1$, we can write equation (iii) as

$$\mathbf{M} = (N\mu_0 \mathbf{p}_B^2/kT)(\mathbf{H} + \gamma\mathbf{M})$$

$$\therefore \quad \mathbf{M}\left(1 - \frac{\gamma N\mu_0 \mathbf{p}_B^2}{kT}\right) = \frac{N\mu_0 \mathbf{p}_B^2 \mathbf{H}}{kT} \qquad ...(iv)$$

Using this equation, we have, magnetic susceptibility as

$$\chi_m = \frac{\mathbf{M}}{\mathbf{H}} = \frac{N\mu_0 \mathbf{p}_B^2/k}{T - (\gamma N\mu_0 \mathbf{p}_B^2/k)} = \frac{C}{T - \theta} \qquad ...(v)$$

where, $C = N\,\mu_0\,\mathbf{p}_B^2/k$ and $\theta = \gamma C$.

For the model, we have a relation which is identical in form with the **Curie Weiss law.** For a ferromagnetic material, C and θ can be determined from measurements of susceptibility as a function of temperature. The value of γ for a ferromagnetic material is of the order of 10^3.

(ii) Ferromagnetic Materials below Curie Temperature ($T < T_c$) – The Curie Weiss law given by equation (v) cannot hold for $T \leq \theta$, for then

magnetic susceptibility would pass through a pole and becomes negative, for $T = \theta$, the susceptibility would become infinite. This fact suggests that at $T < \theta$, spontaneous magnetization may occur (i.e., when $\mathbf{H} = 0$, $\mathbf{M}$ is non-vanishing). This will be seen by the following analysis –

For the model considered in the previous section, magnetization when internal field is $\mathbf{H} + \gamma\mathbf{M}$, is given by

$$\mathbf{M} = N\mathbf{p}_B \tanh\left[\frac{\mu_0 \mathbf{p}_B}{kT}(\mathbf{H} + \gamma\mathbf{M})\right]$$

when $\mathbf{H} = 0$, let us see whether we get non-vanishing value of $\mathbf{M}$ or not. From equation (iii) when $\mathbf{H} = 0$,

$$\mathbf{M} = N\mathbf{p}_B \tanh\frac{\mu_0 \mathbf{p}_B \gamma \mathbf{M}}{kT}$$

and
$$\frac{\mathbf{M}}{N\mathbf{p}_B} = \frac{\mathbf{M}}{\mathbf{M}_{sat}} = \tanh\alpha \qquad \text{...(vi)}$$

where
$$\alpha = \frac{\mu_0 \mathbf{p}_B \gamma \mathbf{M}}{kT} \qquad \text{...(vii)}$$

Where $\mathbf{M}_{sat} = N\mathbf{p}_B$ represents the saturation value of magnetization. $\mathbf{M}/\mathbf{M}_{sat}$ as a function of α is shown in fig. 3.6. From equation (vii) putting the value of $\mathbf{M}$, we have

$$\frac{\mathbf{M}}{\mathbf{M}_{sat}} = \frac{\mathbf{M}}{N\mathbf{p}_B} = \frac{kT}{N\gamma\mu_0 \mathbf{p}_B^2}.\alpha = \frac{T}{\theta}.\alpha \qquad \text{...(viii)}$$

Now, for a given temperature T, equation (vii) in a plot of $\mathbf{M}/\mathbf{M}_{sat}$ versus α represents a straight line with a slope equal to T/θ. Because $\mathbf{M}/\mathbf{M}_{sat}$ must satisfy both equations (vi) and (viii), the value of $\mathbf{M}/\mathbf{M}_{sat}$ for a fixed temperature T is given by the intersection of the straight line and $\tanh\alpha$ curve is shown in the fig. 3.6. At temperature $T < \theta$, the two curves intersect and $\mathbf{M}/\mathbf{M}_{sat}$ has some positive value, shows that spontaneous magnetization is present.

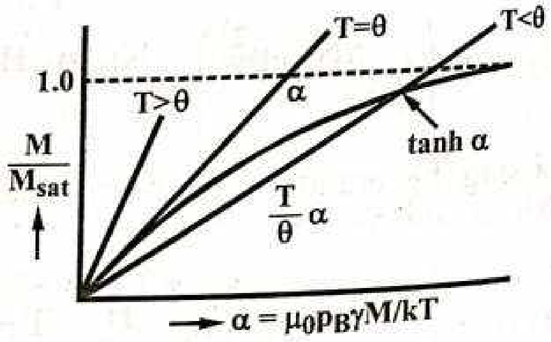


Fig. 3.6 Intersection of Two Curves $\dfrac{M}{M_{sat}}$ *(= tanh α) vs α and* $\dfrac{M}{M_{sat}}\left(=\dfrac{T}{\theta}.\alpha\right)$ *vs α*

At temperature $T \geq \theta$ the intersection of the two curves is only at the origin, clearly showing $\mathbf{M}/\mathbf{M}_{sat} = 0$, i.e., spontaneous magnetization vanishes. When $T = \theta$ the expression (viii) gives $\mathbf{M}/\mathbf{M}_{sat} = \alpha$, but this line is tangent to

the tanh α curve at the point $\alpha = 0$, so when $T \geq \theta$, there is no spontaneous magnetization. The experimental curve showing M/M_{sat} as a function of T/θ for different materials Fe, Co and Ni is shown in fig. 3.7.

The only difference between theoretical interpretation and experimental results is that the theory does not differentiate between the ferromagnetic Curie temperature T_c and paramagnetic Curie temperature θ; however, the difference is not great.

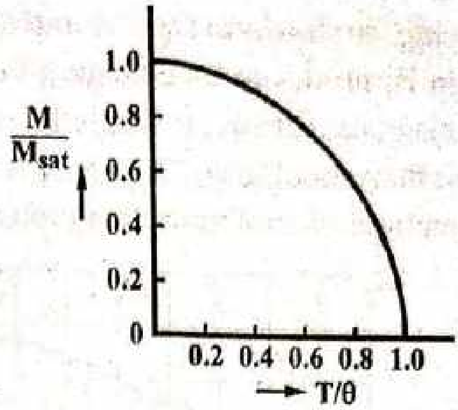


Fig. 3.7 Relative Spontaneous Magnetization as a Function of T/θ for Fe, Co and Ni

Q.11. Draw and explain magnetization curve for a ferromagnetic material.

Ans. The permeability μ of a substance is given by

$$\mu = \frac{B}{H} = \mu_0\mu_r.$$

where, B = Magnitude of flux density, T
H = Magnetic field intensity, A m^{-1}
μ_0 = Permeability of vacuum = 400π nH m^{-1}
μ_r = Relative permeability of substance, dimensionless.

To illustrate the relation of B to H, a graph showing B (ordinate) as a function of H (abscissa) is used. The line or curve showing B as a function of H on such a BH chart is called a ***magnetization curve.***

To measure a magnetization curve for an iron sample, a ring may be cut from the sample. A uniform winding is placed over the ring, forming an iron-cored toroid, as shown in fig. 3.8. If the number of ampere-turns in the toroid is NI, the value of H applied to the ring is

$$H = \frac{NI}{l} \quad \text{A-turns m}^{-1}$$

where, $l = 2\pi R$ and R = Mean radius of the ring or toroid.

This value of H applied to the ring may be called the ***magnetizing force.*** Hence, in general, H is sometimes called by this name. The flux density B in the ring may be regarded as the result of the applied field H and is measured by placing another (secondary) coil over the

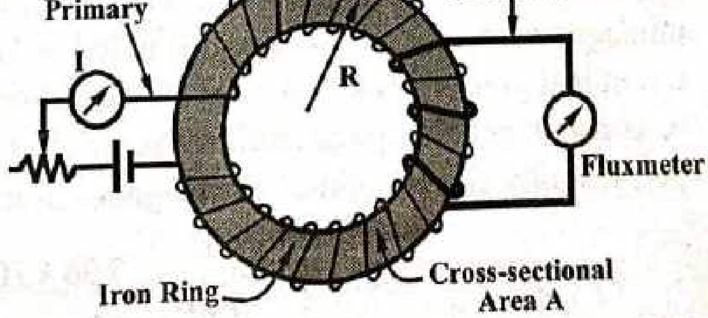
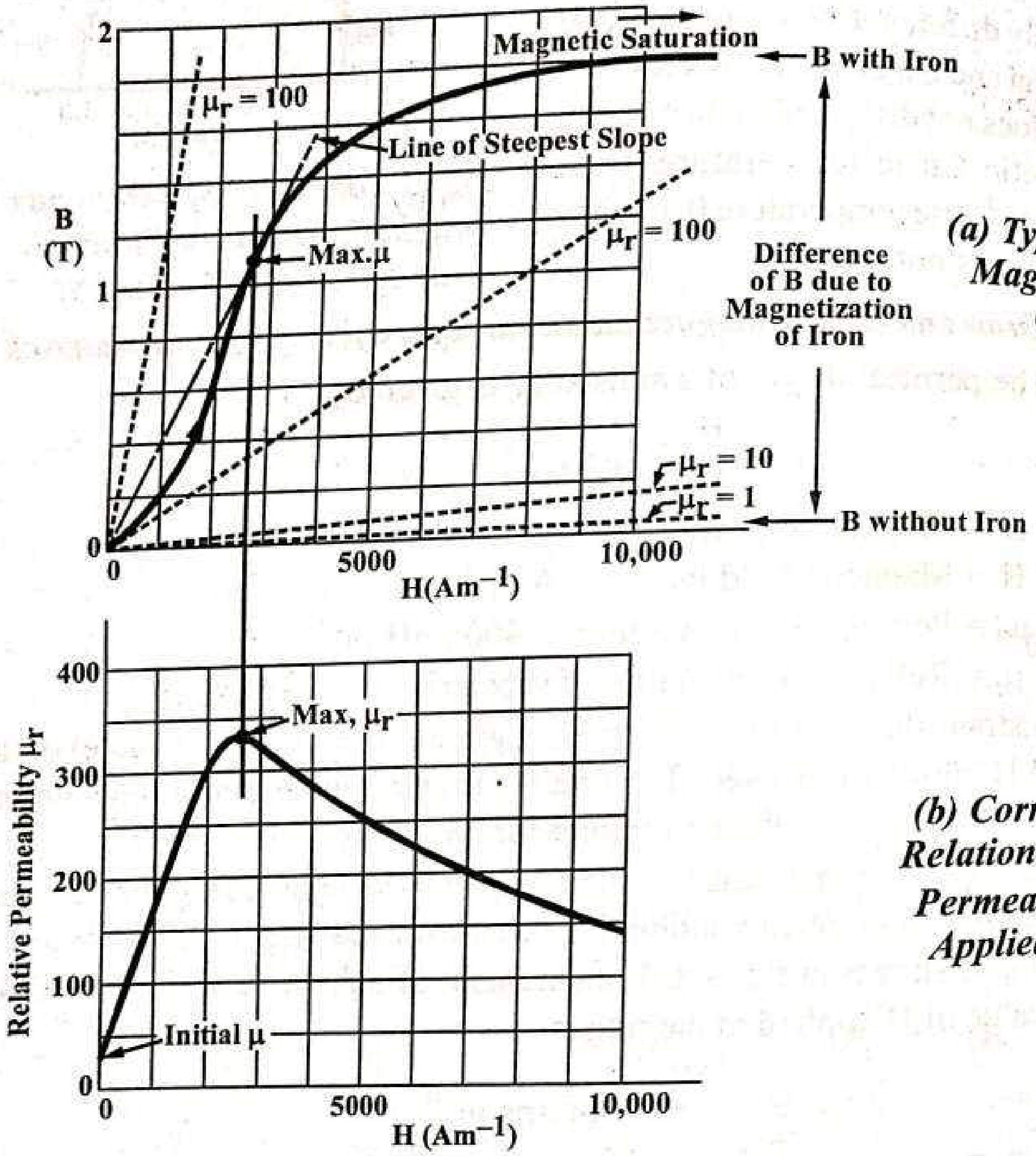


Fig. 3.8 Rowland Ring Method of Obtaining Magnetization Curves

ring, as shown in fig. 3.8 and connecting it to a fluxmeter. For a given change in H, produced by changing the toroid current I, one measures the change in magnetic flux ψ_m through the ring. The change in the flux density B in the ring is then equal to ψ_m/A, where A is the cross-sectional area of the ring. This ring method of measuring magnetization curves was used by Rowland in 1873.



(a) Typical Initial Magnetization Curve

(b) Corresponding Relation of Relative Permeability μ_r to Applied Field H

Fig. 3.9

A typical magnetization curve for a ferromagnetic material is shown by the solid curve in fig. 3.9 (a). The specimen in this case was initially unmagnetized, and the change in B noted as H was increased from 0. By way of comparison, four dashed lines are also shown in fig. 3.9 (a) corresponding to constant relative permeabilities μ_r, of 1, 10, 100, and 1000. The relative permeability at any point on the magnetization curve is given by

$$\mu_r = \frac{B}{\mu_0 H} = 7.96 \times 10^5 \frac{B}{H} \text{ (dimensionless)}$$

where, B = Ordinate of the point, T

H = Abscissa of the point, Am^{-1}.

Note that μ_r is not proportional to the slope of the curve (dB/dH) but to the ratio B/H.

A graph of the relative permeability μ_r as a function of the applied field H, corresponding to the magnetization curve in fig. 3.9 (a) is presented in fig. 3.9 (b). The maximum relative permeability, and therefore the ***maximum permeability***, is at the point on the magnetization curve with the largest ratio of B to H. This is designated "Max μ." It occurs at the point of tangency with the straight line of steepest slope that passes through the origin and also intersects the magnetization curve [dash-dot line in fig. 3.9 (a)]. The magnetization curve for air or vacuum is given by the dashed line for $\mu_r = 1$ (almost coincident with the H axis) in fig. 3.9 (a).

The magnetization curve shown in fig. 3.9 (a) is an ***initial-magnetization curve***. That is, the material is completely demagnetized before the field H is applied. As H is increased, the value of B rises rapidly at first and then more slowly. At sufficiently high values of H the curve tends to become flat, as suggested by fig. 3.9 (a). This condition is called ***magnetic saturation.***

Although the B/H ratio (or permeability) has significance for the ***initial magnetization curve,*** and the ***normal magnetization curve*** discussed later, this is not the case for magnetization loops and some other magnetization curves we consider presently, where the ratio B/H may become infinite.

The magnetization curve starting at the origin has a finite slope giving an ***initial permeability.*** Therefore, the relative-permeability curve in fig. 3.9 (b) starts with a finite permeability for infinitesimal fields.

The initial-magnetization curve may be divided into two sections – (i) the steep section and (ii) the flat section, the point P of division being on the upper bend of the curve (fig. 3.10). The steep section corresponds to the condition of easy magnetization, while the flat section corresponds to the condition of difficult, or hard magnetization.

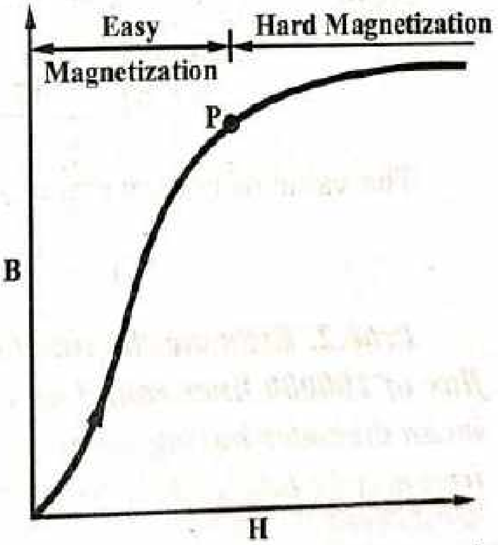


Fig. 3.10 Regions of Easy and Hard Magnetization of Initial-magnetization Curve

Q.12. Discuss about the magnetization characteristics of ferromagnetic materials. ***(R.G.P.V., Dec. 2015, Nov. 2018)***

Or

Discuss some of the magnetization characteristics of ferromagnetic materials. ***(R.G.P.V., May 2019)***

Ans. Refer the ans. of Q.10 and Q.11.

NUMERICAL PROBLEMS

Prob.1. An iron ring of 20 cm mean diameter has a cross section of 100 cm², is wound with 400 turns of a conducting wire. Calculate the exciting current required to establish a flux density of 1 Wb/m². If the relative permeability of iron is 1000. What is the value of energy stored ? ***(R.G.P.V., Dec. 2015)***

Sol. Given, $D = 20$ cm $= 0.2$ m $\quad (l = \pi D = 0.2\pi$ m$)$

Area of cross-section, $A = 100$ cm^2 $= 100 \times 10^{-4}$ m^2

Number of turns, $N = 400$, $\mu_r = 1000$

Magnetic flux density, $B = 1$ Wb/m^2

The magnetic flux density B is given by the equation,

$$B = \mu_0 \mu_r \frac{NI}{l}$$

The exciting current,

$$I = \frac{B \times l}{\mu_0 \mu_r N}$$

$$= \frac{1 \times 0.2\pi}{4\pi \times 10^{-7} \times 1000 \times 400} = \mathbf{1.25\ amp.} \qquad \text{Ans.}$$

Now,

$$L = \frac{\mu_0 \mu_r A N^2}{l}$$

$$= \frac{4\pi \times 10^{-7} \times 1000 \times 100 \times 10^{-4} \times (400)^2}{0.2\pi} = 3.2\ \text{H}$$

The value of energy stored is given by

$$E = \frac{1}{2} L I^2 = \frac{1}{2} \times 3.2 \times (1.25)^2 = \mathbf{2.5\ J} \qquad \text{Ans.}$$

Prob.2. Estimate the number of ampere turns necessary to produce a flux of 100000 lines round an iron ring of 6 cm² cross-section and 20 cm mean diameter having an air gap 2 mm wide across it. Permeability of the iron may be taken 1200. Neglect the leakage flux outside the 2 mm air gap. ***(R.G.P.V., June 2010)***

Sol. Given,

Area of cross-section of the ring,

$A = 6$ cm^2 $= 6 \times 10^{-4}$ m^2

Mean diameter of the ring,

$D_m = 20$ cm $= 0.2$ m

Length of the air gap,

$l_g = 2$ mm $= 2 \times 10^{-3}$ m

Flux set-up the ring,

$\phi = 100000$ lines

$= 100000 \times 10^{-8} = 0.001$ Wb

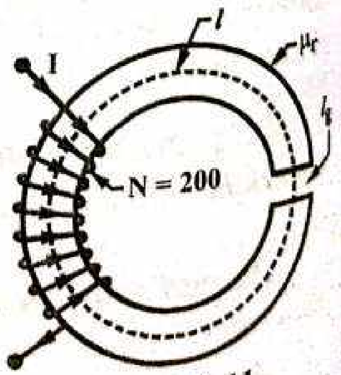


Fig. 3.11

Relative permeability of iron, $\mu_r = 1200$

The magnetic circuit is shown in fig. 3.11.

Mean length of ring, $l_m = \pi D = \pi \times 0.2 = 0.6283$ m

Length of air gap, $l_g = 0.002$ m

Length of iron path, $l_i = 0.6283 - 0.002 = 0.6263$ m

Now, M.M.F = Flux × Reluctance

Ampere turns required for iron path,

$$AT_i = \phi \times \frac{l_i}{A\mu_0\mu_r} = 0.001 \times \frac{0.6263}{6 \times 10^{-4} \times 4\pi \times 10^{-7} \times 1200} = 692.21 \text{ AT}$$

Ampere turns required for air gap,

$$AT_g = \phi \times \frac{l_g}{A\mu_0} = \frac{0.001 \times 0.002}{6 \times 10^{-4} \times 4\pi \times 10^{-7}} = 2652.58 \text{ AT}$$

Total ampere turns required to produce the given flux

$$= AT_i + AT_g = 692.21 + 2652.58 = \mathbf{3344.79\ AT} \qquad \textbf{Ans.}$$

Prob.3. An iron ring of 400 cm mean circumference is made from round iron of cross-section 20 cm². Its permeability is 500. If it is wound with 400 turns, what current would be required to produce a flux of 0.001 Wb ? ***(R.G.P.V., Feb. 2010)***

Sol. Given, mean length of magnetic path $l_m = 400$ cm = 4 m

Area of cross-section of iron ring 'A' = 20×10^{-4} m²

Permeability $\mu_r = 500$, N = 400, and flux (ϕ) = 0.001 Wb.

Now, M.M.F. = Flux × Reluctance

$$NI = \phi \times \frac{l_m}{A\mu_0\mu_r}$$

or

$$I = \frac{\phi l_m}{AN\mu_0\mu_r} = \frac{0.001 \times 4}{20 \times 10^{-4} \times 400 \times 4\pi \times 10^{-7} \times 500} = \mathbf{7.958\ A} \quad \textbf{Ans.}$$

SELF INDUCTANCE AND MUTUAL INDUCTANCE, ENERGY IN LINEAR MAGNETIC SYSTEMS, COIL CONNECTED IN SERIES

Q.13. What is inductance ?

Ans. The inductance is defined as the rate of total magnetic flux linkage to the current through the coil and is generally represented by the symbol L.

$$\therefore \qquad L = \frac{d\lambda}{dI} = \frac{Nd\phi}{dI}$$

If the flux varies linearly with I then above equation becomes as,

$$\frac{d\phi}{dI} = \frac{\phi}{I}$$

$$\therefore \quad L = \frac{\lambda}{I} = \frac{N\phi}{I}$$

The unit of inductance is ***henry.*** The inductance of a coil is said to be 1 henry if current in the coil changes at rate of 1 A/sec, an E.M.F. of 1 volt is induced in it, or if the flux linkage with the coil changes at the rate of 1 Wb-turn/ A.

Q.14. What do you mean by self inductance ?

Ans. Self inductance of a circuit is the property of the circuit by which any change in the circuit current induces an E.M.F. in the circuit to oppose the change of current.

Mathematically,

$$L = \frac{d\lambda}{dI} = \frac{Nd\phi}{dI}$$

and induced E.M.F. is given as,

$$e = -L\frac{dI}{dt}$$

Q.15. Write down the various method to find the coefficient of self inductance.

Ans. Coefficient of self inductance may be calculated by three methods which are given below –

(i) First Method – The coefficient of self inductance of a coil is defined as the weber-turns per ampere in the coil. Here weber-turns is the flux linkages of the coil.

Let us consider a solenoid having N-turns carrying a current of I amperes. If the flux produced is ϕ webers, then the weber-turns are $N\phi$.

$$\therefore \quad L = \frac{N\phi}{I} \text{ henry}$$

(ii) Second Method – The flux produced in a solenoid is given by,

$$\phi = \frac{NI}{l/\mu_0\mu_r A} \text{ or } \frac{\phi}{I} = \frac{N}{l/\mu_0\mu_r A}$$

$$\because \quad L = \frac{N\phi}{I} \text{ or } L = \frac{N.N}{l/\mu_0\mu_r A} = \frac{N^2\mu_0\mu_r A}{l}$$

This gives the value of self inductance in terms of dimensions of the solenoid.

(iii) Third Method – Self inductance L is given by,

$$L = \frac{N\phi}{I} \text{ or } N\phi = LI \text{ or } -N\phi = -LI$$

Differentiating both of sides with respect to t,

$$-\frac{d}{dt}(N\phi) = -L\frac{dI}{dt} \text{ or } \frac{-Nd\phi}{dt} = \frac{-LdI}{dt}$$

$$e_L = -L\frac{dI}{dt} \qquad \left(\because e_L = \frac{-Nd\phi}{dt}\right)$$

If $\frac{dI}{dt} = 1$ A/sec. and $e_L = 1$ volt, then L = 1 H.

Hence, a coil has a self inductance of one henry if one volt is induced in it when current through it changes at the rate of 1 A/sec.

Q.16. Define mutual inductance.

Ans. Mutual inductance of a coil is defined as the ability of one coil (or circuit) to produce an E.M.F. in a nearby coils by induction when the current in the first coil changes. This is also possible that the second coil can also induced an E.M.F. in the first coil when the current in the second coil changes. This ability of reciprocal induction is measured in terms of the coefficient of mutual inductance M.

Q.17. Explain the various methods to find the coefficient of mutual inductance.

Ans. The coefficient of mutual inductance can be calculated by three methods, which are given below –

(i) First Method – Let us assume that there are two magnetically coupled coils which have N_1 and N_2 turns respectively. Then, coefficient of mutual inductance between two coils is defined as the weber-turns in one coil due to one ampere current in the other.

Let a current of I_1 ampere flowing in the first coil produce a flux ϕ_1 webers in it. It is assumed that whole of this flux links with the second coil. Then,

$$M = \frac{N_2\phi_1}{I_1}$$

If weber-turns in second coil due to one ampere current in the first coil i.e., $(N_2\phi_1/I_1) = 1$ then M = 1 H.

Therefore, two coils are said to have a mutual inductance of 1 henry if one ampere current when flowing in one coil produces flux linkages of one weber-turn in the other.

(ii) Second Method – We can represent the coefficient of mutual inductance in terms of the dimensions of the two coils.

Flux in the first coil,

$$\phi_1 = \frac{N_1I_1}{l/\mu_0\mu_rA} \text{ Wb or } \frac{\phi_1}{I_1} = \frac{N_1A\mu_0\mu_r}{l}$$

$$\because \qquad M = \frac{N_2\phi_1}{I_1} = \frac{\mu_0\mu_r A N_1 N_2}{l}$$

Also, $$M = \frac{N_1N_2}{l/\mu_0\mu_r A} = \frac{N_1N_2}{S}$$

where $S = l/\mu_0\mu_r A$ = Reluctance.

(iii) Third Method – Coefficient of mutual inductance is given as

$$M = \frac{N_2\phi_1}{I_1} \text{ or } N_2\phi_1 = MI_1 \text{ or } -N_2\phi_1 = -MI_1$$

Differentiating both of sides with respect to t, we get

$$\frac{-d}{dt}(N_2\phi_1) = -M\frac{dI_1}{dt}$$

$$e_M = -M\frac{dI_1}{dt} \qquad \left(\because \frac{-d}{dt}(N_2\phi_1) = e_M\right)$$

If $\frac{dI_1}{dt} = 1$ A/sec, $e_M = 1$ volt then M = 1 H.

Therefore, two coils are said to have a mutual inductance of one henry if current changing at the rate of 1 A/sec in one coil induces an E.M.F. of one volt in the other.

Q.18. Determine the self inductance of solenoid.

Ans. Let us assume that the length of solenoid be l metres. Cross-sectional area of solenoid be A m^2 and number of turns over it be N.

When solenoid is carrying a current of I ampere, then the magnetic field at the centre of it is given by,

$$H = \frac{NI}{l} \qquad \text{...(i)}$$

If the length of solenoid is sufficiently greater than its diameter, the magnetic field will be same all over the cross-section.

$$\therefore \qquad \phi_m = \mu HA \qquad \text{...(ii)}$$

By substituting the value of H from equation (i) in equation (ii), we get

$$\phi_m = \frac{\mu NIA}{l} \qquad \text{...(iii)}$$

Let us assume that flux linkage be same with all the turns.

$$\therefore \qquad \lambda = N\phi_m \qquad \text{...(iv)}$$

Since inductance is given by,

$$L = \frac{d\lambda}{dI} \qquad \text{...(v)}$$

By substituting the value of λ from equation (iv) in equation (v), we obtain

$$L = \frac{d(N\phi_m)}{dI} = \frac{Nd\phi_m}{dI} \quad ...(vi)$$

By substituting the value of ϕ_m from equation (iii) in equation (vi), we have

$$L = N\frac{d}{dI}\left(\frac{\mu NIA}{l}\right) = N\left(\frac{\mu NA}{l}\right) = \frac{\mu N^2 A}{l}$$

$$= \frac{N^2}{l/\mu A} = \frac{N^2}{l/\mu_0\mu_r A} = \frac{N^2}{S} \qquad (\because \mu = \mu_0\mu_r)$$

where S = Reluctance of the magnetic circuit.

Practically, the inductance of a short solenoid is given by,

$$L = K\frac{\mu_0\mu_r N^2 A}{l}$$

where K is a Nagoka's constant. It depends on the ratio of length to diameter of the solenoid.

Q.19. Prove that $M = k\sqrt{L_1 L_2}$. What is the range of variation in k ?

Ans. Consider two magnetically coupled coils A and B having N_1 and N_2 turns respectively. Their individual coefficients of self inductances are

$$L_1 = \frac{N_1^2}{l/\mu_0\mu_r A} \text{ and } L_2 = \frac{N_2^2}{l/\mu_0\mu_r A}$$

The flux ϕ_1 produced in coil A due to a current I_1 ampere is

$$\phi_1 = \frac{N_1 I_1}{l/\mu_0\mu_r A}$$

Let a fraction k_1 of this flux i.e., $k_1\phi_1$ be linked with coil B. Then

$$M = \frac{k_1\phi_1 \times N_2}{I_1} \qquad \text{where } k_1 \le 1$$

Substituting the value of ϕ_1, we have

$$M = \frac{k_1 N_1 N_2}{l/\mu_0\mu_r A} \quad ...(i)$$

Similarly for flux ϕ_2 produced in B due to I_2 ampere in it is

$$\phi_2 = \frac{N_2 I_2}{l/\mu_0\mu_r A}$$

Let a fraction k_2 of this flux i.e. $k_2\,\phi_2$ be linked with coil A. Then

$$M = \frac{k_2\phi_2 \times N_1}{I_2}$$

On substituting the value of ϕ_2, we get

$$M = \frac{k_2 N_1 N_2}{l/\mu_0 \mu_r A} \quad \text{...(ii)}$$

Multiplying equations (i) and (ii), we have

$$M^2 = k_1 k_2 \frac{N_1^2 \times N_2^2}{l/\mu_0 \mu_r A \times l/\mu_0 \mu_r A}$$

or $$M^2 = k_1 k_2 L_1 L_2 \text{ or } M = \sqrt{k_1 k_2 L_1 L_2}$$

Let $$k = \sqrt{k_1 k_2} \text{ or } k = k_1 = k_2$$

$\therefore$ $$\mathbf{M = k\sqrt{L_1 L_2}}$$ **Proved.**

Constant k is called the ***coefficient of coupling.***

The value of k lies between 0 and 1, k have zero value when the flux of one coil does not at all link with the other or magnetically isolated whereas when k = 1, the coil is said to be tightly coupled.

Q.20. Derive the expression for the energy in linear magnetic systems.

Ans. The energy stored in the magnetic field is equal to the work done in establishing the field. If the current increasing from 0 to I with the potential difference across the inductor equal to V, then the source is supplying power equal to V. Energy supplied by the source in time dt is VI dt, and if we neglect the resistance then the energy supplied must be stored in the inductor,

$$dW = VI\,dt$$

If the current is increased from 0 to I in time t, then

$$\int dW = \int VI\,dt$$

$$W = \int LI \frac{dI}{dt} dt \qquad \left(\because V = L\frac{dI}{dt}\right)$$

$$= L\int_0^I I\,dI = \frac{L}{2}\left[I^2\right]_0^I$$

$\therefore$ $$W = \frac{1}{2}LI^2$$

$\because$ $$\phi = LI$$

$\therefore$ $$W = \frac{1}{2}\phi I = \frac{\phi^2}{2L}$$

Above equation can be compared with expression for energy stored in capacitors,

$$W = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{Q^2}{2C}$$

Thus, we can see that there is a correspondence between L and C, I and V, ϕ and Q.

Q.21. Write the expression of energy stored in magnetic field in terms of self and mutual inductance.

Ans. Let us consider two coils which are shown in fig. 3.12. The self inductances of the coils are L_1 and L_2 and mutual inductances between them are M_{12} and M_{21}.

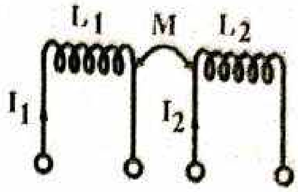


Fig. 3.12

We assume that the coil 2 is open circuited and the current in the coil 1 is increased to I_1. Thus the energy stored in the coil 1 is given by,

$$W_1 = \frac{1}{2} L_1 I_1^2 \qquad ...(i)$$

When the coil 2 is connected to supply and current increased to I_2 in time period of t second, then the extra energy required is,

$$W_2 = \frac{1}{2} L_2 I_2^2 + \text{Energy required to maintain } I_1 = \frac{1}{2} L_2 I_2^2 + \int_0^t v_1 I_1 dt$$

where $v_1 = -e = M_{21} \dfrac{dI_2}{dt}$

$$\therefore \qquad W_2 = \frac{1}{2} L_2 I_2^2 + \int_0^{I_2} M_{21} I_1 \, dI_2$$

$$= \frac{1}{2} L_2 I_2^2 + M_{21} I_1 \int_0^{I_2} dI_2$$

$$= \frac{1}{2} L_2 I_2^2 + M_{21} I_1 I_2 \qquad ...(ii)$$

Thus, the total energy stored is calculated by adding equations (i) and (ii), we get

$$\therefore \qquad W_m = \frac{1}{2} L_1 I_1^2 + M_{21} I_1 I_2 + \frac{1}{2} L_2 I_2^2$$

When the currents increase in reverse order, then the result would have been the same but middle term changed by $M_{12} I_1 I_2$. Thus we see that the energy cannot be different in two cases, i.e.,

$$M_{12} = M_{21} = M$$

$$\therefore \qquad W_m = \frac{1}{2} L_1 I_1^2 + \frac{1}{2} L_2 I_2^2 \pm M I_1 I_2$$

Here ± sign depends upon whether the mutual coupling is additive or subtractive.

Q.22. Write short note on coil (inductance) connected in series.

Ans. Consider two coils of self-inductances L_1 and L_2 are connected in series and a mutual inductance is M(in henry). The voltage induced in coil-1 and coil-2 are V_{L_1} and V_{L_2}' respectively. The two coils are connected in series in the following two ways –

(i) When their fields (or M.M.Fs.) are additive i.e., their fluxes are set-up in the same directions (see fig. 3.13). In this case, an inductance of each coil is increased by mutual inductance M.

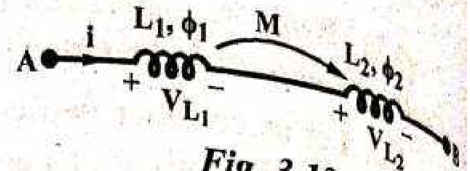


Fig. 3.13

From fig. 3.13, we have

$$V_{L_1} = L_1\frac{di}{dt} + M\frac{di}{dt} = (L_1 + M)\frac{di}{dt} \quad ...(i)$$

and
$$V_{L_2} = L_2\frac{di}{dt} + M\frac{di}{dt} = (L_2 + M)\frac{di}{dt} \quad ...(ii)$$

Total voltage is,

$$V_L = V_{L_1} + V_{L_2}$$
$$= (L_1 + M)\frac{di}{dt} + (L_2 + M)\frac{di}{dt}$$
$$= \frac{di}{dt}[L_1 + 2M + L_2]$$
$$= [L_1 + L_2 + 2M]\frac{di}{dt}$$

The total inductance is given by

$$L = L_1 + L_2 + 2M \quad ...(iii)$$

(ii) When their fields are subtractive i.e., their fluxes are set-up in the opposite direction (see fig. 3.14). In this case, an inductance of each coil is decreased by mutual inductance M.

In fig. 3.14, where the coils are still series connected but the flux of both the coils oppose each other.

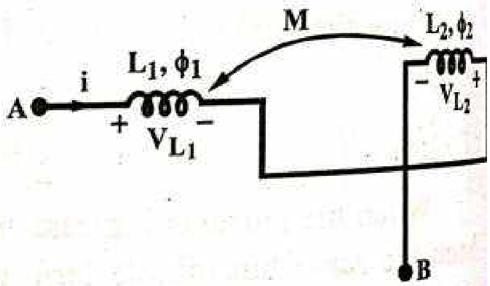


Fig. 3.14

$$V_{L_1} = (L_1 - M)\frac{di}{dt}$$

and
$$V_{L_2} = (L_2 - M)\frac{di}{dt}$$

Total voltage is,

$$V_L = (L_1 - M)\frac{di}{dt} + (L_2 - M)\frac{di}{dt}$$
$$= (L_1 + L_2 - 2M)\frac{di}{dt}$$

Thus, the total inductance is given by

$$L = L_1 + L_2 - 2M \quad ...(iv)$$

NUMERICAL PROBLEMS

Prob.4. Two coils, A and B, have self inductances of 350 μH and 120 μH respectively. A current of 5 amps through coil A produces flux linkages of 200μWb turns in coil B. Calculate – (i) the mutual inductance between the coils (ii) the coupling coefficient and (iii) average e.m.f. induced in coil B if a current of 5 amps in coil A is reversed at a uniform rate in 0.2 second.

Sol. (i) The mutual inductance,

$$M = \frac{\text{Flux linkages of coil B}}{\text{Current in coil A}} = \frac{200 \times 10^{-6}}{5} = \mathbf{40\ \mu H} \qquad \textbf{Ans.}$$

(ii) The coupling coefficient is given by

$$M = k\sqrt{L_1 L_2}$$

$$\therefore \quad k = \frac{M}{\sqrt{L_1 L_2}} = \frac{40 \times 10^{-6}}{\sqrt{350 \times 10^{-6} \times 120 \times 10^{-6}}} = \mathbf{0.195} \qquad \textbf{Ans.}$$

(iii) The average induced e.m.f.,

The average induced e.m.f. induced in coil B, if a current of 5 A in coil A is reversed at a uniform rate in 0.2 second

$$e_2 = M \times \frac{di}{dt} = 40 \times 10^{-6} \times \frac{5}{0.2} = 1\ \text{mV} = \mathbf{1.0\ mV} \qquad \textbf{Ans.}$$

Prob.5. An inductance of a coil is 0.10 H. The coil has 100 turns. Determine –

(i) Total magnetic flux through the coil when the current is 2 A.

(ii) Energy stored in the magnetic field.

(iii) Voltage induced in the coil, when current is reduced to zero in 0.01 second.

Sol. Given, L = 0.10 H, I = 2 A, N = 100

(i) Inductance of the coil is given by

$$L = \frac{N\phi}{I}$$

Magnetic flux

$$\phi = \frac{LI}{N} = \frac{0.10 \times 2}{100} = 2 \times 10^{-3}\ \text{Wb} = \mathbf{2\ mWb} \quad \textbf{Ans.}$$

(ii) Energy stored in magnetic field is given by

$$E = \frac{1}{2}LI^2 = \frac{1}{2} \times 0.10 \times (2)^2 = \mathbf{0.20\ J} \qquad \textbf{Ans.}$$

(iii) Voltage induced in the coil is,

$$e = L\frac{di}{dt} = 0.10 \times \frac{2}{0.01} = \mathbf{20\ V}$$

Ans.

A.C. EXCITATION IN MAGNETIC CIRCUITS, MAGNETIC FIELD PRODUCED BY CURRENT CARRYING CONDUCTOR, FORCE ON A CURRENT CARRYING CONDUCTOR

Q.23. Write short note on A.C. excitation in magnetic circuits.

Ans. A magnetic circuit have closed core excited with A.C. supply is shown in fig. 3.15.

Let core flux varies sinusoidal. Thus,

$$\phi(t) = \phi_{max}.\sin \omega t$$
$$= B_{max}.A.\sin \omega t \qquad [\phi_{max} = B_{max}.A]$$

where ϕ_{max} = Maximum core flux in weber

B_{max} = Maximum flux density in tesla

A = Area of cross-section in metre^2

ω = Angular velocity = $2\pi f$ (in rad/s)

f = Frequency of excitation in hertz.

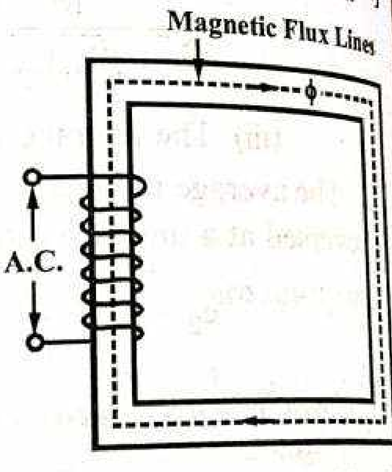


Fig. 3.15 Magnetic Circuit Excited with an A.C. Supply

Voltage induced in N-turn winding is

$$e(t) = \omega N\phi_{max} \cos \omega t = E_{max}.\cos \omega t$$

where $E_{max} = \omega N\, \phi_{max}$

$$= 2\pi f\, N\, B_{max}\, A.$$

R.M.S. value of induced voltage is

$$E_{r.m.s.} = \frac{2\pi f\, N\, B_{max}.A}{\sqrt{2}}$$
$$= \sqrt{2}\,\pi f\, N\, B_{max}.A = 4.44\, Nf\, B_{max}.A.$$

To produce magnetic flux in the core, required current in the exciting winding known as exciting current.

$\therefore$ Exciting current, $I_\phi = \dfrac{Hl}{N}$, where l = Length of magnetic path.

or for r.m.s. value $I_{\phi r.m.s.} = \dfrac{H_{r.m.s.}l}{N}$

$\therefore$ r.m.s. volt-ampere required to excite the core is

$$E_{r.m.s.}\, I_{\phi r.m.s.} = \sqrt{2}\pi f\, N\, B_{max}.A.\frac{H_{r.m.s.}l}{N}$$
$$= \sqrt{2}\pi f\, B_{max}.A.H_{r.m.s.}l \quad (\because A \times l = V = \text{Volume})$$

or Power input $= \sqrt{2}\pi f\, B_{max}.H_{r.m.s.}V = 4.44f\, B_{max}.H_{r.m.s.}V$

The exciting current supplies the m.m.f. required to produce the core flux and the power input associated with the energy in the magnetic field in the core.

Q.24. Find the magnetic field produced by current carrying conductor.

Ans. The magnetic field associated with a current carrying conductor depends upon the following factors –

(i) Magnitude of current

(ii) The direction of flow of current.

The two conductors carry the same current in opposite directions as shown in fig. 3.16 and carrys the same current in opposite direction and their field so produced have different direction. When these two conductors are laid side by side, the two fields so produced will cancel each other, thereby resulting in zero magnetic effect. Therefore the magnetic effect produced by two conductors laid side by side. The same current carrying in opposite directions is nil. The magnetic effect will be twice compared to one such conductor alone, when they carry the same current in the same direction.

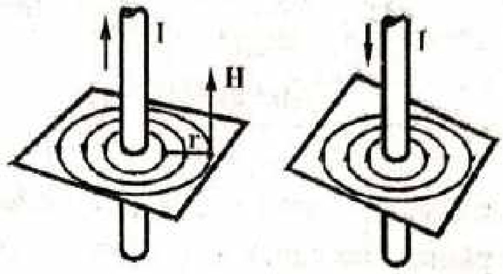


Fig. 3.16 Magnetic Field Produced by Current Carrying Conductor

Ampere's circuit law states that the line integral of the magnetic field intensity H along any close path is exactly equal to the total current enclosed by the path.

Mathematically,

$$\oint H\, dl = \Sigma I \quad \text{...(i)}$$

Let us consider a conductor carrying current I as shown in fig. 3.16. The magnetic field intensity H at a distance r from the conductor is expressed as –

$$\oint H\, dl = I$$

$$H.2\pi r = I$$

$$H = \frac{I}{2\pi r} \quad \text{...(ii)}$$

When instead of single conductor, there are N number of conductors enclosed by the closed path, then

$$H = \frac{N.I}{2\pi r} \quad \text{...(iii)}$$

Q.25. Find the magnetic field intensity due to current carrying conductor of large size.

Or

Derive for the field H at any point (P) due to ∞ long current carrying straight conductor.

Ans. In determining the magnetic field due to a current carrying conductor, we consider a straight wire of length l carrying a static current I at a point P which is at a distance r from the wire as shown in fig. 3.17. The magnetic field intensity **dH** due to a small element I dl is obtained as,

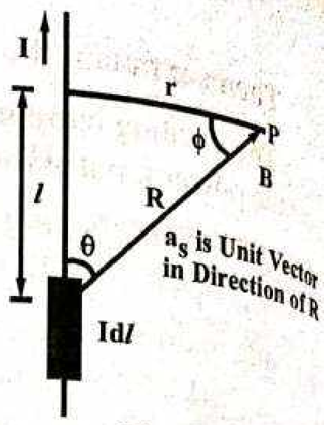


Fig. 3.17

$$dH = \frac{I d\boldsymbol{l} \times \mathbf{a_R}}{4\pi R^2} \quad \text{(from the Biot-Savart law)}$$

$$dH = \frac{I dl \sin(90^\circ + \phi)}{4\pi R^2} \mathbf{a}_u \qquad \text{....(i)}$$

where $\mathbf{a}_u$ is unit vector perpendicular to plane containing dl and $\mathbf{a}_R$ into the plane. The equation (i) can be equivalently written in the form as,

$$\mathbf{dH} = \frac{I dl \cos\phi}{4\pi R^2} \mathbf{a}_u \qquad \text{...(ii)}$$

where θ and φ are the complementary angles. The magnetic field intensity due to entire length l is expressed in the form,

$$\mathbf{H} = \frac{I}{4\pi}\left[\int_0^l \frac{\cos\phi \, dl}{R^2}\right]\mathbf{a}_u = \frac{I}{4\pi}\left[\int_0^l \frac{r/R}{R^2} dl\right]\mathbf{a}_u$$

where in fig. 3.17, $\cos\phi = r / R$.

$$\mathbf{H} = \frac{Ir}{4\pi}\left[\int_0^l \frac{dl}{R^3}\right]\mathbf{a}_u = \frac{Ir}{4\pi}\left[\int_0^l \frac{dl}{\left(r^2 + l^2\right)^{3/2}}\right]\mathbf{a}_u \qquad \text{...(iii)}$$

where in fig. 3.17, r is constant and $R = \sqrt{r^2 + l^2}$. By taking r^3 out from denominator, we can write as,

$$\mathbf{H} = \frac{Ir}{4\pi r^3}\left[\int_0^l \frac{dl}{\left[1 + \left(\frac{l}{r}\right)^2\right]^{3/2}}\right]a_u \qquad \text{...(iv)}$$

In fig. 3.17, we make the assumption l/r = tan φ to determine the integral. Therefore, ...(v)

$$l = r \tan\phi$$

On differentiating w.r.t. φ, we obtain

$$dl = r \sec^2\phi \, d\phi$$

$$1 + \left(\frac{l}{r}\right)^2 = 1 + \tan^2\phi = \sec^2\phi$$

Then we obtain the limits of transformation from 0 to ϕ.

$$\mathbf{H} = \frac{Ir}{4\pi r}\left[\int_0^{\phi}\frac{r\sec^2\phi}{\sec^3\phi}d\phi\right]\mathbf{a}_u = \frac{Ir^2}{4\pi r^3}\left[\int_0^{\phi}\cos\phi\, d\phi\right]\mathbf{a}_u$$

$$\mathbf{H} = \frac{I}{4\pi r}[\sin\phi]_0^{\phi}\,\mathbf{a}_u = \frac{I}{4\pi r}\sin\phi\,\mathbf{a}_u$$

For a wire of infinite length extending it at both ends such as $-\infty$ to $+\infty$, the limits of integration would be $-\pi/2$ to $+\pi/2$ which gives the expression for magnetic field intensity in the form,

$$\mathbf{H} = \frac{I}{4\pi r}\times 2\mathbf{a}_u = \frac{I}{2\pi r}\times\mathbf{a}_u$$

Q.26. Write expressions for Lorentz force. On what factors does this force depend ?

Ans. If a charged particle moves in a magnetic field, a force acts on the particle due to the magnetic field which is called Lorentz force.

The magnitude of Lorentz force depends on the following –

(i) The force F is directly proportional to the magnetic field B, i.e.,

$$F \propto B$$

(ii) The force F is directly proportional to the charge q, i.e.

$$F \propto q$$

(iii) The force F is directly proportional to the velocity V of the particle, i.e.

$$F \propto V$$

(iv) The force F is directly proportional to the sine of the angle θ, i.e.,

$$F \propto \sin\theta$$

Combining the all above statements, we get

$$F \propto BqV\sin\theta$$

$$F = KBqV\sin\theta$$

where, K is a constant (i.e., K = 1)

Then, $$F = BqV\sin\theta \quad \text{...(i)}$$

For $\theta = 0°$, we get

$$F = BqV\sin 0 = 0 \quad \text{...(ii)}$$

For $\theta = 90°$, we get

$$F = BqV\sin 90° = BqV \quad \text{...(iii)}$$

Q.27. Write expressions for the force acting on a current carrying conductor placed in a magnetic field. On what factors does this force depend? If the conductor makes an angle 0° and 90° with the magnetic field in each, what will be the force ?

Or

Explain how current carrying conductor when placed in a magnetic field experiences a force ? ***(R.G.P.V., Dec. 2015)***

Or

Derive a relation that gives the value of force on a current carrying conductor. **(R.G.P.V., May 2019)**

Ans. When a current carrying conductor is placed in a magnetic field, the conductor experiences a force in a direction perpendicular to both the direction of magnetic field and the direction of current flowing in the conductor. This force is also called the Lorentz force and the direction of this force is also obtained either by the Fleming's left hand rule or by the right hand palm rule.

Fig. 3.18 shows a conductor placed in a uniform magnetic field B. The length of the conductor is l and a current I is flowing in the conductor.

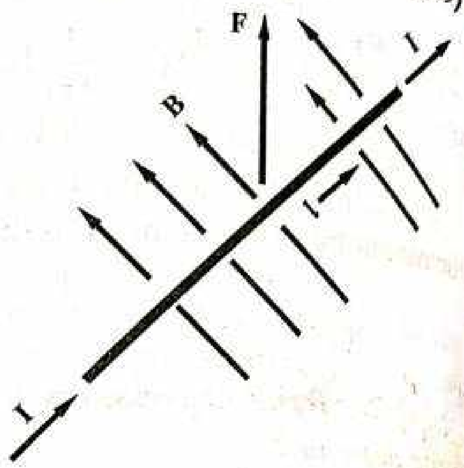


Fig. 3.18 Force on a Current Carrying Conductor in a Uniform Magnetic Field

The magnitude of the force acting on a current carrying conductor depends on the following factors –

(i) The force F is directly proportional to the current flowing in the conductor, i.e., $F \propto I$

(ii) The force F is directly proportional to the intensity of magnetic field, i.e., $F \propto B$

(iii) The force F is directly proportional to the length l of the conductor, i.e., $F \propto l$

(iv) The force F is proportional to the sine of the angle θ (i.e., sin θ) which the length of conductor makes with the direction of magnetic field, i.e.,

$$F \propto \sin\theta$$

Combining the all above statements, we get

$$F \propto BIl\sin\theta$$

or
$$F = KBIl\sin\theta$$

where K is a constant whose value depends on the system of measurement. In C.G.S. system and S.I. system the unit of B is chosen such that the value of K is 1.

$$\therefore \quad F = BIl\sin\theta$$

If the conductor makes 0° with the magnetic field, then the force becomes

$$F = BIl\sin 0^\circ = 0$$

If the conductor makes 90° with the magnetic field, then the force becomes

$$F = BIl\sin 90^\circ = BIl$$

Q.28. Discuss the force between two long and parallel current carrying conductors.

Ans. Fig. 3.19 shows two straight current carrying conductor AB and CD placed parallel to each other at a separation R in the plane, carrying currents I_1 and I_2 respectively in the opposite direction.

The magnetic field produced by the infinitely long current carrying conductor AB at any point of conductor CD is given by,

$$B_1 = \frac{\mu_0}{4\pi} \times \frac{2I_1}{R} \qquad ...(i)$$

and the direction of this magnetic field B_1 is perpendicular to plane of inwards.

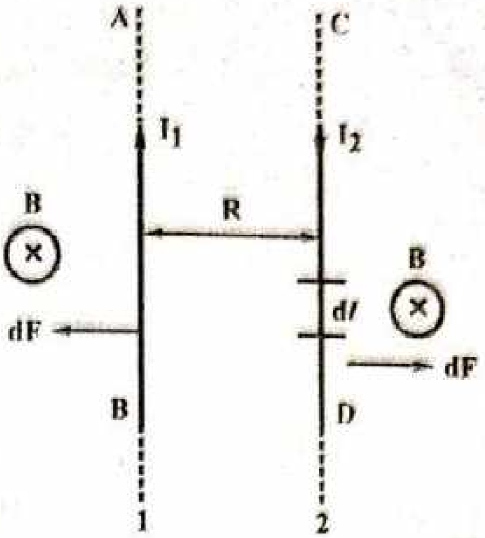


Fig. 3.19

The conductor CD carrying current I_2 is placed in this magnetic field B_1 perpendicular to the field. Thus it will experiences a force (called Lorentz force) perpendicular to both direction of current in it and the direction of magnetic field B_1. The Lorentz force acting on length l of the conductor CD is given by,

$$F = I_2 B_1 \, l \sin 90°$$

or

$$F = I_2 \, B_1 \, l \qquad ...(ii)$$

Using equations (i) and (ii), we get

$$F = \frac{\mu_0}{4\pi} \times \frac{2I_1 I_2 l}{R} \qquad ...(iii)$$

Hence the force acting on unit length of conductor CD is given by,

$$\frac{F}{l} = \frac{\mu_0}{4\pi} \times \frac{2I_1 I_2}{R} \qquad \text{(Repulsion)}$$

It should be noted that if current flows in the same direction in the two conductors placed parallel to each other, the force acting between the conductors is attractive. On the other hand, if current flows in these conductors in opposite direction, a repulsive force acts between two conductors.

NUMERICAL PROBLEMS

Prob.6. A single phase 230 V, 50 Hz supply is connected to the coil (see fig. 3.20), the coil has 200 turns and the parameters of the core are as follows –

Length of core = 100 cm, cross-sectional area of core A = 20 cm² and relative permeability of core μ_r = 3000. Determine –

(i) Flux density in the core

(ii) Current in the coil.

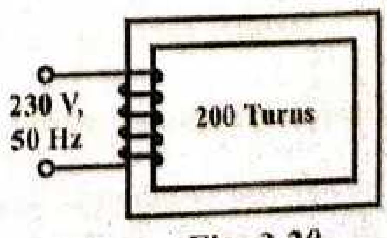


Fig. 3.20

Sol. Given, $N = 200$, $A = 20 \text{ cm}^2 = \mu_r = 3000.$

(i) We know that

$$E = 4.44 \, f \, N \, \phi_{max}$$

or $$\phi_{max} = \frac{E}{4.44\ f\ N} = \frac{230}{4.44 \times 50 \times 200}$$

$$= 5.18 \times 10^{-3}\ Wb = 5.18\ mWb$$

$$B_{max} = \frac{\phi_{max}}{A} = \frac{5.18 \times 10^{-3}}{20 \times 10^{-4}} = 2.59\ T$$

$$B = 2.59 \sin 2 \times 3.14 \times 50\ t$$

$\therefore$ $$= \mathbf{2.59 \sin 314\ t}$$ Ans.

(ii) $$B_{max} = \mu_0 \mu_r\ H_{max}$$

or $$H_{max} = \frac{B_{max}}{\mu_0 \mu_r} = \frac{2.59}{4\pi \times 10^{-7} \times 3000} = 687.02\ At/m$$

$$I_{max} = \frac{H_{max}}{N} \times l = \frac{687.02 \times 100 \times 10^{-2}}{200} = 3.4\ A$$

$$i = I_{max} \sin 2\pi ft$$

$$= 3.4 \sin 2 \times 3.14 \times 50\ t$$

$\therefore$ $$i = \mathbf{3.4 \sin 314\ t}$$ Ans.

INDUCED VOLTAGE, LAWS OF ELECTROMAGNETIC INDUCTION, DIRECTION OF INDUCED E.M.F.

Q.29. Explain induced E.M.F. and their types. ***(R.G.P.V., April 2009)***

Ans. Induced e.m.f. may be divided into two categories –

(i) Dynamically Induced E.M.F. – Dynamically induced e.m.f. is induced by the movement of the conductor in a magnetic field of flux density B Wb/m^3.

Consider the condition shown in fig. 3.21 (a) when conductor A cuts across at right angles to the flux.

Suppose 'l' is its length lying within the field and let it move a distance dx in time dt.

Hence, Flux cut = l.dx × B webers

Time taken = dt seconds

Hence, according to Faraday's laws, the e.m.f. induced in it is equal to the rate of change of flux linkages $= Bl\frac{dx}{dt} = Blv$ volt, where $\frac{dx}{dt}$ = Velocity

If the conductor A moves at an angle θ with the direction of flux as shown in fig. 3.21 (b), then the e.m.f. induced dynamically $e = Blv \sin\theta$ volts

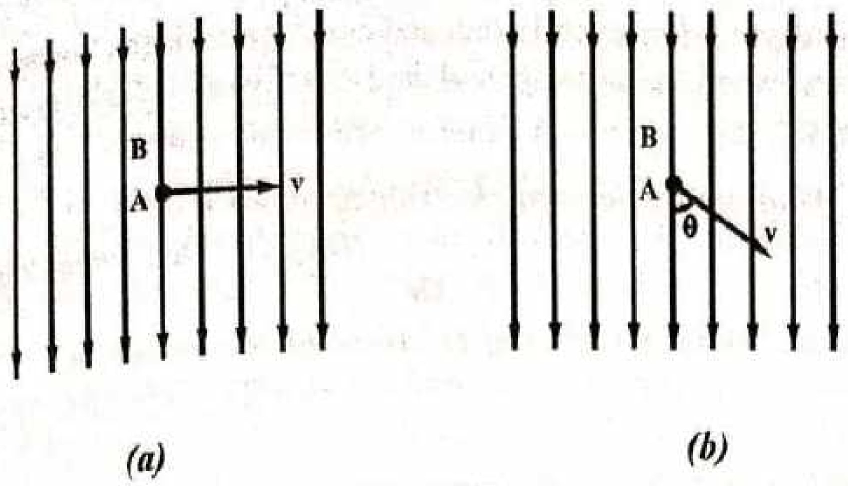


Fig. 3.21

(ii) Statically Induced E.M.F. – When a conductor or coil remains stationary and the flux linking with these conductors or coil undergo a change, an e.m.f. is induced in the conductors.

It is sub-divided into two categories –

(a) Self induced e.m.f. (b) Mutually induced e.m.f.

(a) Self Induced E.M.F. – Any electrical circuit in which the change of current is accompanied by the change of flux, and therefore by an induced e.m.f. according to Faraday's law of electromagnetic induction is called ***self induced e.m.f.*** in the coil.

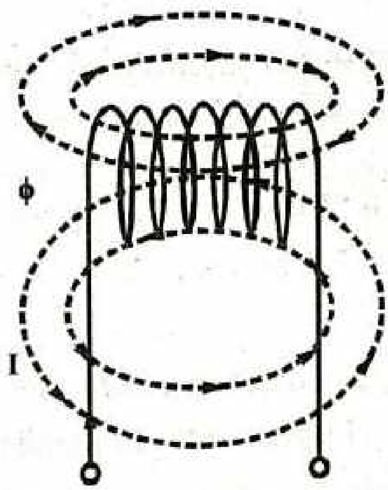


Fig. 3.22 Self Induced E.M.F.

$$e = -L\frac{dI}{dt} \text{ volt}$$

where $L = \dfrac{N\phi}{I} = \dfrac{\text{Flux linkage}}{\text{Current}}$ is called self inductance of the coil, and its unit is henry.

The negative sign indicates that if the current is increasing, this e.m.f. will oppose the increase in current and vice-versa.

(b) Mutually Induced E.M.F. – An e.m.f. induced in one coil by the influence of the other coil is called ***mutually induced e.m.f.***

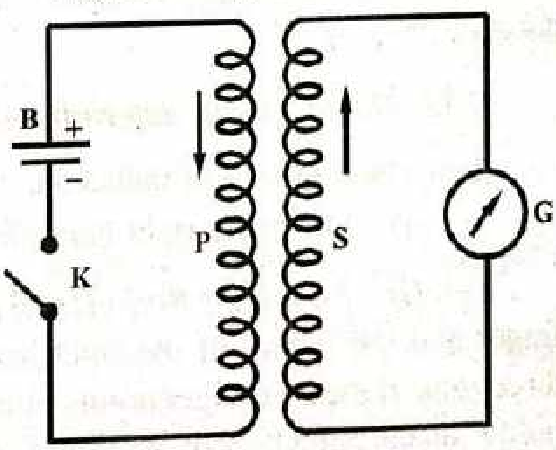


Fig. 3.23 Mutually Induced E.M.F.

$$e_m = M\frac{dI}{dt}$$

where M is mutual inductance between two coils.

The concept of dynamically induced e.m.f. gave rise to the development of generators, whereas statically induced e.m.f. was helpful in developing transformers.

Q.30. What are the laws of electromagnetism ?

(R.G.P.V., Dec. 2006, 2007, 2011)

Or

State and explain the laws of electromagnetic induction.

(R.G.P.V., Dec. 2015, June 2016)

Or

Explain Faraday's law of electromagnetic induction.

(R.G.P.V., May 2018)

Or

Discuss the laws of electromagnetic induction. (R.G.P.V., Nov. 2018)

Ans. There are two laws given by Faraday, known as ***Faraday's law*** of electromagnetic induction.

First Law – According to the first law, whenever a conductor cuts magnetic flux, an e.m.f. is induced in the circuit, resulting in an induced current in the circuit.

Or

Whenever the magnetic flux associated or linked with a closed circuit changes, an e.m.f. is induced in that circuit.

Second Law – It states that the magnitude of an induced e.m.f. generated in a coil is directly proportional to the rate of change of magnetic flux.

Hence,
$$e = -N\frac{d\phi}{dt} \text{ volt}$$

where, e = Induced e.m.f., N = Number of turns in the coil

ϕ = Flux linkages in the coil.

Usually a minus sign is taken in the expression to signify the fact that induced e.m.f. generated a current tending to oppose the increase of flux through the coil.

Q.31. How will you determine the direction of induced e.m.f. ?

Ans. The direction of induced e.m.f. can be determined by two methods –

(i) Fleming's right hand rule (ii) Lenz's law.

(i) Fleming's Right Hand Rule – Stretch the forefinger, the middle finger and the thumb of the right hand in the three mutually perpendicular directions. If the forefinger points in the direction of magnetic flux, the thumb points in the direction of motion of the conductor relative to the magnetic field, then the middle finger represents the direction of the induced e.m.f.

(ii) Lenz's Law – The direction of the statically induced e.m.f. can be obtained with the help of Lenz's law, which states that the direction of induced e.m.f. is always such that it tends to set up a current opposing the change of flux responsible for producing that e.m.f.

Fleming's right hand rule is used to obtain the direction of induced e.m.f., whereas Lenz's law is normally used to fixed the direction of statically induced e.m.f.

SINGLE PHASE TRANSFORMER – GENERAL CONSTRUCTION, WORKING PRINCIPLE, E.M.F. EQUATION, EQUIVALENT CIRCUITS, PHASOR DIAGRAM

Q.32. What is transformer ? Give its classification.

Ans. The transformer is a static (or stationary) electromagnetic device, which transfers electric power from one circuit to another without change in frequency.

The transformer basically works on the mutual induction between the two circuits linked by a common magnetic field. It consists of two windings, in which electric energy is fed from the A.C. supply mains, is called ***primary winding*** and the other which receives energy is called ***secondary winding***. Both windings are physically isolated but coupled magnetically.

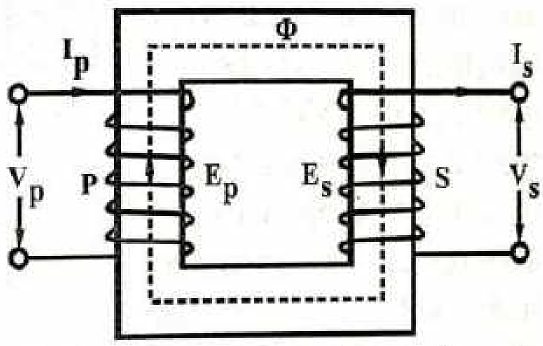


Fig. 3.24 Elementary Transformer

The transformer can be classified as follows –

(i) On the basis of phase
  (a) Single phase transformer
  (b) Three phase transformer.

(ii) On the basis of construction
  (a) Shell type transformer
  (b) Core type transformer.

(iii) On the basis of working
  (a) Step up transformer
  (b) Step down transformer.

(iv) On the basis of power ratings
  (a) Distribution transformer
  (b) Power transformer.

Q.33. Discuss the general construction of single phase transformer.

Or

What are core type and shell type transformers ? (R.G.P.V., Dec. 2006)

Or

Explain the construction detail of transformer. [R.G.P.V., Nov. 2018(O)]

Ans. The main parts of a transformer are two coils and a laminated steel core. The two coils are insulated from each other as well as from the steel core. The core of the transformer is prepared from laminations silicon steel

and sheet steel assembled to give a continuous magnetic path. At usual flux densities, the silicon steel material has low hysteresis losses. The core is laminated to reduce the eddy current loss. The laminations are insulated from each other by a light coating of varnish or by an oxide layer. The thickness of laminations varies from 0.35 mm for a frequency of 50 Hz to 0.5 mm for a frequency of 25 Hz.

Constructionally there are two types of transformers i.e., core type transformer and shell type transformer. They are differ from each other by the manner in which the windings are wound around the magnetic core.

Core Type Transformer – In the core type transformer, the windings surround a considerable part of the core, i.e., the half turns of primary and secondary windings are placed on each limb (core).

Generally, circular coils are used in core type transformer because of their mechanical strength. Such cylindrical coils are wound in helical layers with the different layers insulated from each other by paper, cloth, micarta board or cooling ducts. Schematic diagram is shown of core type transformer in fig. 3.25.

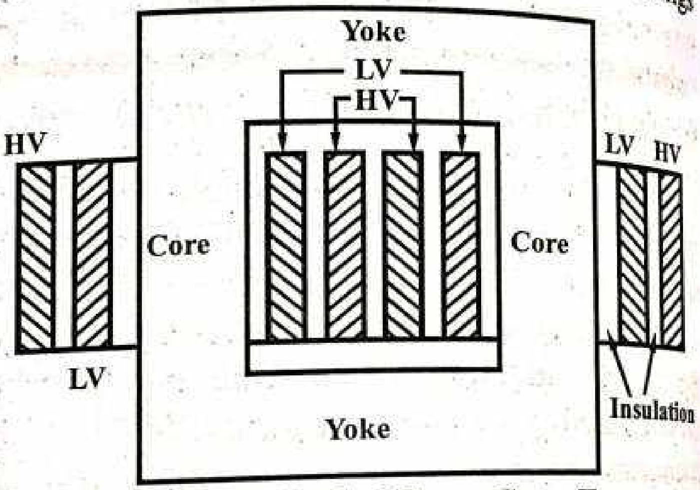


Fig. 3.25 Single Phase Core Type Transformer

Shell Type Transformer – In the shell type transformer, the steel core surrounds a major part of the windings. A shell-type transformer may have a simpler rectangular shape as shown in fig. 3.26. Total flux Φ is produced on central leg, the half of flux go towards the each side leg at the yoke section thus the cross-section of side limb make half that of central limb.

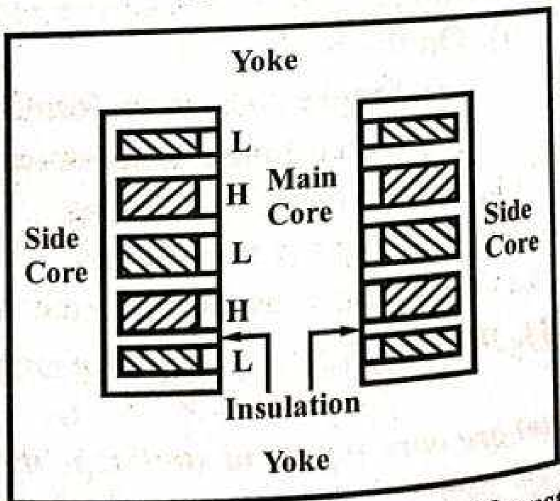


Fig. 3.26 Single Phase Shell Type Transformer

Q.34. Explain the construction and classification of single phase transformer.
(R.G.P.V., Dec. 2016)

Ans. Refer the ans. of Q.33 and Q.32.

Q.35. Explain the principle of working of a single-phase transformer with the help of neat diagram indicating the flux. ***(R.G.P.V., March/April 2010)***

Or

Explain the principle of operation of transformer with suitable sketches. ***(R.G.P.V., Dec. 2011)***

Ans. A transformer works on the principle of electromagnetic induction between two windings.

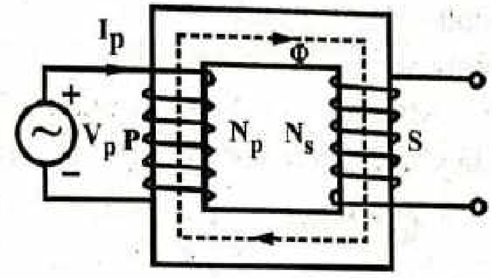


Fig. 3.27

The two windings posses high mutual inductances. If one winding (called primary winding) is connected to a source of alternating voltage, an alternating flux is set-up in the laminated core, most of which is linked with the other winding (called secondary winding) in which it produces mutually induced e.m.f. of the secondary winding circuit is closed, a current flows in it and so electric energy is transferred from the first winding to the secondary winding.

The number of turns in secondary winding are less than the primary winding then received voltage is less than the source voltage and if the number of turns in the secondary winding is more than the primary winding, the received voltage is more than the source voltage.

Q.36. Discuss in brief about the construction and basic principle of operation of transformer. ***(R.G.P.V., Dec. 2010)***

Or

Explain principle of working of a transformer. Explain core and shell type transformer with diagram. ***(R.G.P.V., May 2018)***

Ans. Refer the ans. of Q.33 and Q.35.

Q.37. Explain the purpose of breather in a transformer.

Ans. In large sized transformers where complete air-tight construction is not possible, chambers known as breathers are provided to permit the oil inside the tank to expand and contract as the temperature of oil increases or decreases. A breather mounted on the transformer tank contains calcium chloride or silica gel, which has the tendancy to extract moisture from air. In the absence of breather, moisture in the air would have entered the transformer oil, the presence of which is quite detrimental to oil.

Q.38. Explain the purpose of conservator in a transformer.

Ans. The conservator is an air-tight cylindrical metal drum supported horizontally on the transformer lid or on a nearby wall. It should be provided with access hole, through which it can be cleaned from oil sludge. Under operating condition, temperature of transformer material rise. Due to this change in

temperature, the oil in the tank undergoes the process of expansion and contraction. The conservator takes up this expansion and contraction of oil without allowing the oil to come in contact with the air. Normally, the conservator capacity varies upto 10 to 12 percent of the oil volume in the tank.

Q.39. Explain the purpose of bushing in a transformer.

Ans. Bushings are mounted on the top of the transformer tank. The bushing consists of a current carrying part in the form of the conducting rod, and a porcelain cylinder installed in the hole of the cover and used to isolate the current carrying part. Ordinary porcelain insulators can be used upto a voltage rating of 33 kV. Condenser bushings or oil filled terminal bushings used for higher voltages.

Q.40. Show that the transformer is a constant flux device.
(R.G.P.V., June 2016)

Ans. When the secondary winding is connected to the load, the secondary current flows in the secondary winding. The magnitude and angle of the secondary current is determined by the load connected. The secondary current I_s is in phase with V_s if the load is resistive, it lags if the load is inductive and it leads if the load is capacitive.

Now, this secondary current produces its own flux ϕ_s in the core which opposes the main primary flux ϕ produced by no load current I_0. This secondary flux demagnetizes the primary flux hence the primary flux weakens and the primary induced emf E_1 is reduced for a moment. Hence, more current flows from the primary. This secondary mmf N_sI_s is called demagnetizing mmf.

The additional current flowing in the primary due to above effect is I'_s which is called load component of the primary current. This current is anti-phase with I_s. This additional primary current produces its own flux ϕ'_s which is opposite to the ϕ_s but in phase with primary flux ϕ. Hence, these two fluxes cancel each other out. Hence, the magnetizing effect of secondary current is neutralized by additional primary current within a moment as the secondary current flows.

Hence, the total flux in the transformer is almost constant, whatever the load conditions. Thus, the transformer is called a constant flux device.

Hence, $\qquad \phi_s = \phi'_s$

$\therefore \qquad N_sI_s = N_PI's$

$$I'_s = \frac{N_s}{N_P} \times I_s = KI_s.$$

Q.41. What is voltage transformation ratio ? How is it related with current transformation ratio ? ***(R.G.P.V., Dec. 2006, Nov./Dec. 2007)***

Or

What is meant by turn ratio in transformer ? ***(R.G.P.V., Dec. 2011)***

Or

Derive an E.M.F. equation for a single phase transformer.
(R.G.P.V., Dec. 2013, June 2016, Dec. 2016)
Or

A coil wound on an iron core is excited from an A.C. source at voltage V(rms). Derive the expression for maximum flux in the core. Why is it independent of the core reluctance ? ***(R.G.P.V., June 2014)***
Or

Derive an expression for induced e.m.f. in a transformer in terms of frequency, the maximum value of flux and the number of turns on the windings. ***(R.G.P.V., Dec. 2015)***

Ans. Let, N_p = Number of turns in primary winding
N_s = Number of turns in secondary winding
Φ_m = Maximum flux in the core = $B_m \times A$
B_m = Maximum flux density in the core
A = Area of cross-section of the core
f = Frequency of A.C. input in Hz.

Flux Φ increases from its zero value to maximum value Φ_m in one quarter of the cycle, i.e., in 1/4f second, as shown in fig. 3.28.

$\therefore$ Average rate of change of flux $= \dfrac{\Phi_m}{1/4f} = 4f\Phi_m$ Wb/s or volts

But we know that, rate of change of flux per turn is equal to induced e.m.f. in volts.

$\therefore$ Average e.m.f./turn = $4f\Phi_m$ volt.

If flux Φ varies sinusoidally, then r.m.s. value of induced e.m.f. is obtained by multiplying the average value with form factor.

$\because$ Form factor

$$= \frac{\text{r.m.s. value}}{\text{Average value}} = 1.11$$

$\therefore$ r.m.s. value of e.m.f./turn

$$= 1.11 \times 4f\Phi_m = 4.44f\Phi_m \text{ volts}$$

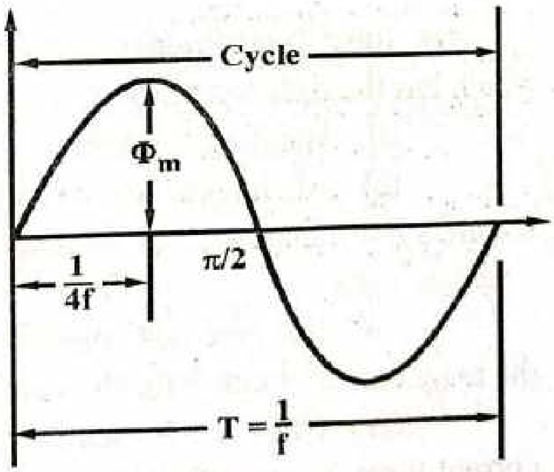


Fig. 3.28 Sinusoidal Wave for Alternating Voltage

Now, r.m.s. value of induced e.m.f. in the whole primary winding

= (Induced e.m.f./turn) × No. of primary turns

$$E_p = 4.44\, f N_p B_m . A \quad (\because B_m . A = \Phi_m) \qquad \ldots(i)$$

Similarly, r.m.s. value of the e.m.f. induced in secondary winding is

$$E_s = 4.44\, f N_s B_m . A \qquad \ldots(ii)$$

Dividing equation (i) by equation (ii), we get

$$\frac{E_P}{E_s} = \frac{N_P}{N_s} = \frac{1}{K} \text{ or } \frac{E_s}{E_P} = \frac{N_s}{N_P} = K \quad ...(iii)$$

where K is known as ***voltage transformation ratio.***

If K > 1, then transformer is called ***step up transformer.*** And if K < 1, then transformer is called ***step down transformer.***

For an ideal transformer,

$$\text{Input VA} = \text{Output VA}$$

$$V_P I_P = V_s I_s \text{ or } \frac{I_s}{I_P} = \frac{V_P}{V_s} = \frac{1}{K} \quad ...(iv)$$

Hence currents are in the inverse ratio of the voltage transformation ratio.

By solving equations (iii) and (iv), we get

$$\frac{E_s}{E_P} = \frac{I_P}{I_s} = \frac{N_s}{N_P}$$

Q.42. Write basic principle of operation of transformer and derive its E.M.F. equation. ***(R.G.P.V., Dec. 2017)***

Ans. Refer the ans. of Q.35 and Q.41.

Q.43. What are the assumptions made for an ideal transformer ? Draw the equivalent circuit and phasor diagram of an ideal transformer. ***(R.G.P.V., Dec. 2012)***

Ans. **Ideal Transformer** – An ideal transformer is an imaginary transformer which has the following properties –

(i) Winding resistances are negligible.

(ii) All the flux set-up by the primary links the secondary windings i.e., all the flux is confined to the magnetic core.

(iii) The core has constant permeability, i.e., the magnetization curve for the core is linear.

(iv) The core losses (hysteresis and eddy current losses) are negligible, i.e., 100% efficient.

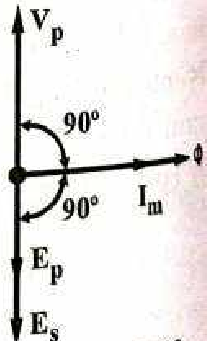


Fig. 3.29

The phasor diagram for an ideal transformer is shown in fig. 3.29. However, it is impossible to realize such type of a transformer.

Equivalent Circuit – The equivalent circuit of an ideal transformer is drawn in fig. 3.30. Here,

$$\overline{V}'_s = a\overline{V}_s \quad ...(i)$$

and

$$\overline{I}'_s = \frac{1}{a}\overline{I}'_s \quad ...(ii)$$

Equations (i) and (ii) are called 'the secondary voltage and current referred to the primary'.

Similarly,

$$\overline{V}_p' = \frac{1}{a}\overline{V}_p \quad ...(iii)$$

$$\overline{I}_p' = a\overline{I}_p' \quad ...(iv)$$

as 'the primary voltage and current referred to the secondary'.

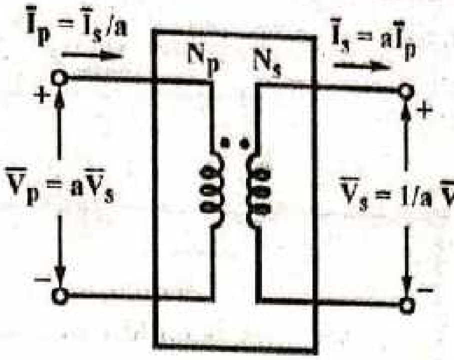


Fig. 3.30 Equivalent Circuit of Ideal Transformer

Q.44. Describe the principle of operation of single phase transformer. What is ideal transformer and transformation ratio ? (R.G.P.V., June 2017)

Ans. Refer the ans. of Q.35, Q.43, and Q.41.

Q.45. What is equivalent circuit ? Draw exact and approximate equivalent circuit of a transformer. Explain in brief how these equivalent parameters are determined. (R.G.P.V., June 2009)

Or

Draw the equivalent circuit of a transformer and explain how the secondary parameters are transferred to primary ? (R.G.P.V., June 2010)

Ans. For developing transformer equivalent circuit, we first consider the primary winding. The flux linking the primary winding may be divided into two components as the resultant mutual flux and the primary leakage flux.

From fig. 3.31 (a) which shows the equivalent circuit of transformer $(R_p + jX_p)$ and $(R_s + jX_s)$ are the leakage impedances of the primary and secondary windings respectively, and the voltage V_p' is treated as a voltage drop in the direction of I_1. The magnitude of V_p' depends on F, N_p and Φ_{max} because $|V_p'| = |E_p|$.

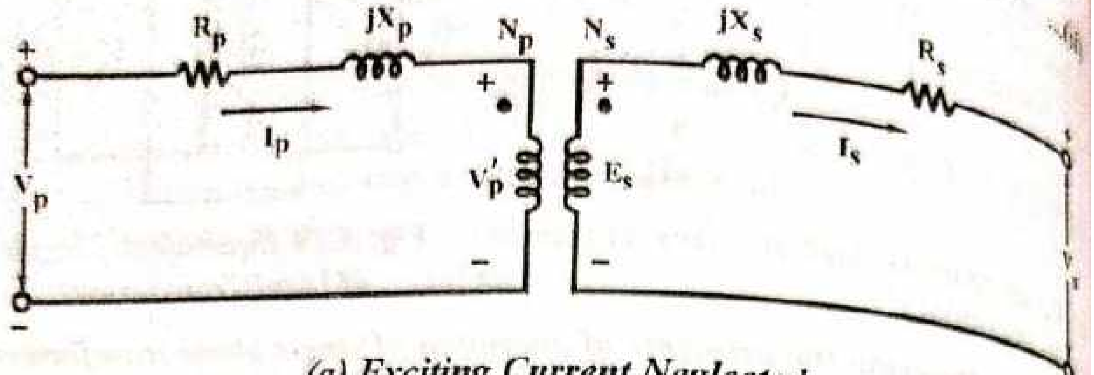
The primary current I_p consists of two components [fig. 3.31 (a)]. One component I_p' is the load component and counteracts the secondary M.M.F. I_sN_s completely. The other component is exciting current I_e which is composed of I_c and I_m. The resistance R_c in parallel with V_p' represents the core loss P_c, so that

and

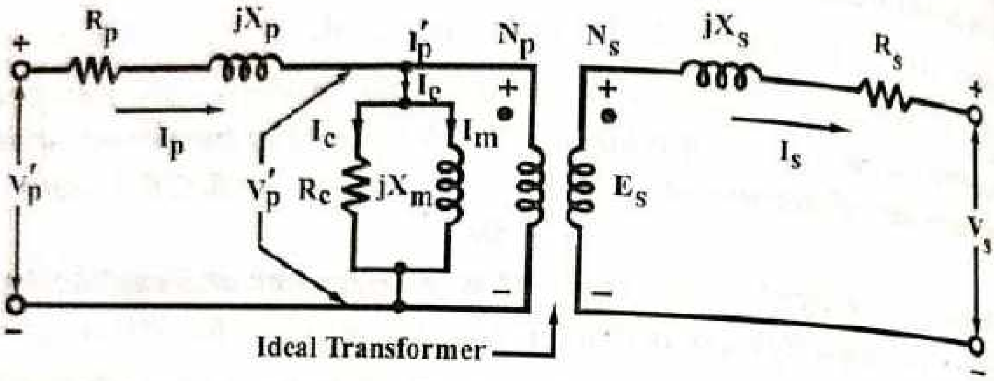
$$\left.\begin{aligned} P_c &= I_c^2R_c = V_p'I_c = \frac{(V_p')^2}{R_c} \\ R_c &= \frac{V_p'}{I_c} \end{aligned}\right\} \quad ...(i)$$

The current I_m lags V_p' by 90° and this can, therefore be represented in the equivalent circuit by a reactance X_m such that

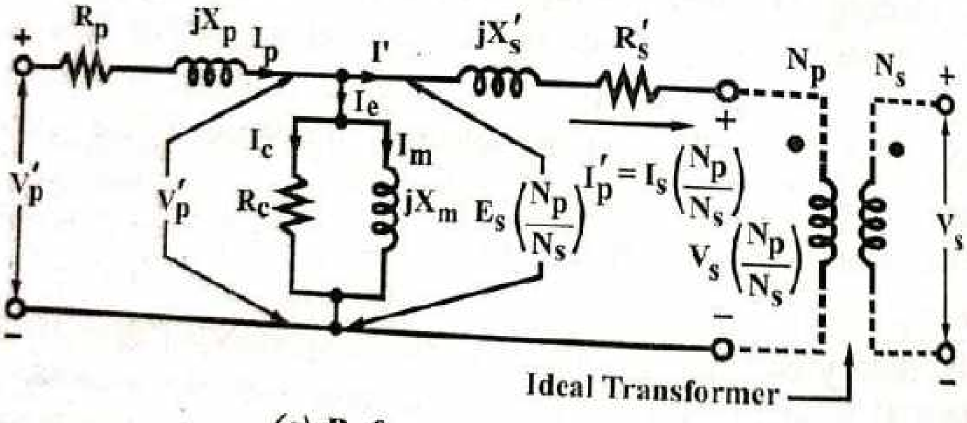
$$X_m = \frac{V_p'}{I_m}$$



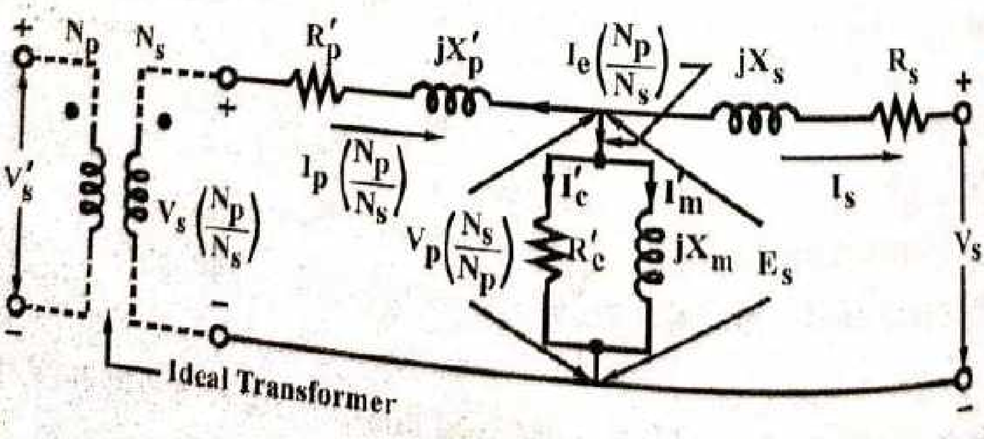
(a) Exciting Current Neglected



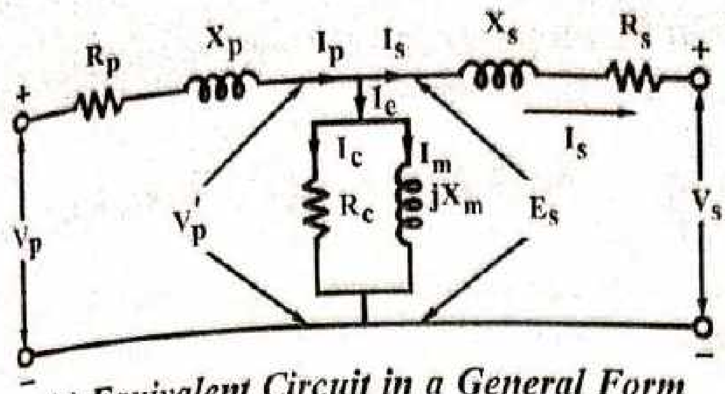
(b) Exact Equivalent Circuit



(c) Referred to Primary



(d) Referred to Secondary



(e) Equivalent Circuit in a General Form
Fig. 3.31

R_c and X_m are shown in fig. 3.31 (b), which is exact equivalent circuit of a transformer. The resistance R_c and reactance X_m are called core loss resistance and magnetizing reactance.

Under normal operation R_c and X_m are treated constant.

Secondary resistance drop, when transferred to primary = $(I_s R_s)\dfrac{N_p}{N_s}$

$$= \left(I_p \frac{N_p}{N_s} R_s\right)\frac{N_p}{N_s} \qquad \left(\text{Putting } I_s = I_p \frac{N_p}{N_s}\right)$$

$$= I_p\left[\left(\frac{N_p}{N_s}\right)^2 .R_s\right] = I_p R_s'$$

where, $$R_s' = R_s.\left(\frac{N_p}{N_s}\right)^2$$

If resistance R_s' is placed in the primary circuit, then the relation between voltages V_p and V_s is uneffected. The resistance R_s' is called the secondary resistance referred to primary. Therefore the total resistance in the primary circuit is

$$R_{ep} = R_p + R_s\left(\frac{N_p}{N_s}\right)^2 = R_p + R_s' \qquad \text{...(iii)}$$

Thus, R_{e1} is called the transformer equivalent (or total) resistance to primary winding.

Equivalent resistance referred to secondary is

$$R_{es} = R_s + R_p\left(\frac{N_s}{N_p}\right)^2 = R_s + R_p' \qquad \text{...(iv)}$$

Secondary leakage reactance drop $I_s X_s$, when transferred to primary is

$$I_s X_s\left(\frac{N_p}{N_s}\right) = I_p\left(\frac{N_p}{N_s}\right)^2 X_s = I_p X_s'$$

X'_s is called the secondary leakage reactance referred to primary. Then the total primary leakage reactance is

$$X_{ep} = X_p + X_s\left(\frac{N_p}{N_s}\right)^2 = X_p + X'_s \quad ...(v)$$

where, X_{ep} is called the equivalent or total leakage reactance referred to primary then the equivalent or total leakage reactance referred to secondary is

$$X_{es} = X_s + X_p\left(\frac{N_s}{N_p}\right)^2 = X_s + X'_p \quad ...(vi)$$

The equivalent (total) leakage impedance referred to primary is

$$Z_{ep} = R_{ep} + jX_{ep}$$

The equivalent (total) leakage impedance referred to secondary is

$$Z_{es} = R_{es} + jX_{es}$$

From the above procedure, it can be shown that

$$Z_{ep} = \left(\frac{N_p}{N_s}\right)^2 Z_{es}$$

and

$$Z_{es} = \left(\frac{N_s}{N_p}\right)^2 Z_{ep}$$

Q.46. Explain basic principle of operation of a transformer. Draw an equivalent circuit of single phase transformer. ***(R.G.P.V., June 2013)***

Ans. Refer the ans. of Q.35 and Q.45.

Q.47. Discuss the construction, working principle, E.M.F. equation and equivalent circuit of single phase transformer. ***(R.G.P.V., Nov. 2018)***

Ans. Refer the ans. of Q.33, Q.35, Q.41 and Q.45.

Q.48. Specify the application of 'equivalent circuit'. (R.G.P.V., June 2014)

Ans. For any electrical device, the equivalent circuit can be drawn if the equations describing its behaviour are known. If any electrical device is to be investigated and analysed further for appropriate changes, its suitable equivalent circuit is essential. The equivalent circuit for electromagnetic devices contains a combination of resistances, inductances, capacitances, voltages etc. Hence, such an equivalent circuit can be investigated and analysed easily by the direct applications of electric circuit theory.

Q.49. Draw the phasor diagram of transformer under –
(i) Resistive load (ii) Inductive load (iii) Capacitive load.
(R.G.P.V., Sept. 2009, June 2010)

Ans. Fig. 3.32 (a), (b) and (c), shows the phasor diagrams of transformer under resistive, inductive and capacitive load respectively.

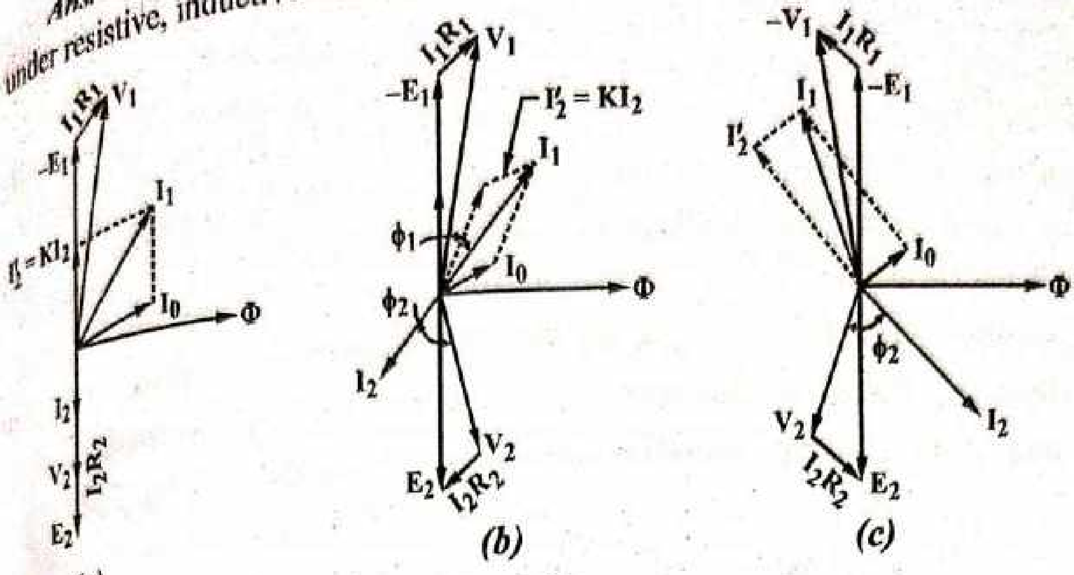


Fig. 3.32

Q.50. Draw phasor diagram of single phase transformer for an inductive load. What variation is observed for a capacitive load ? (R.G.P.V., June 2014)

Ans. Refer the ans. of Q.49.

Q.51. Draw and explain the phasor diagram of a single phase transformer under lagging load condition. (R.G.P.V., Dec. 2010)

Or

Draw the phasor diagram of a single phase transformer with an inductive load. Write down the procedure in steps for drawing the phasor diagram. (R.G.P.V., June 2012)

Or

Draw the complete phasor diagram of a single phase transformer for an inductive load, write the notations used for all voltages and currents used in the phasor diagram. (R.G.P.V., Dec. 2014)

Ans. The secondary circuit of the transformer is considered first and then primary circuit for developing the phasor diagram of a transformer under load.

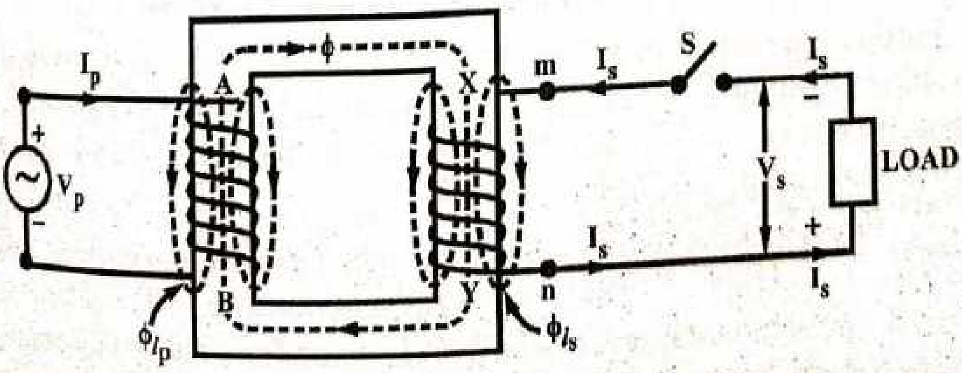


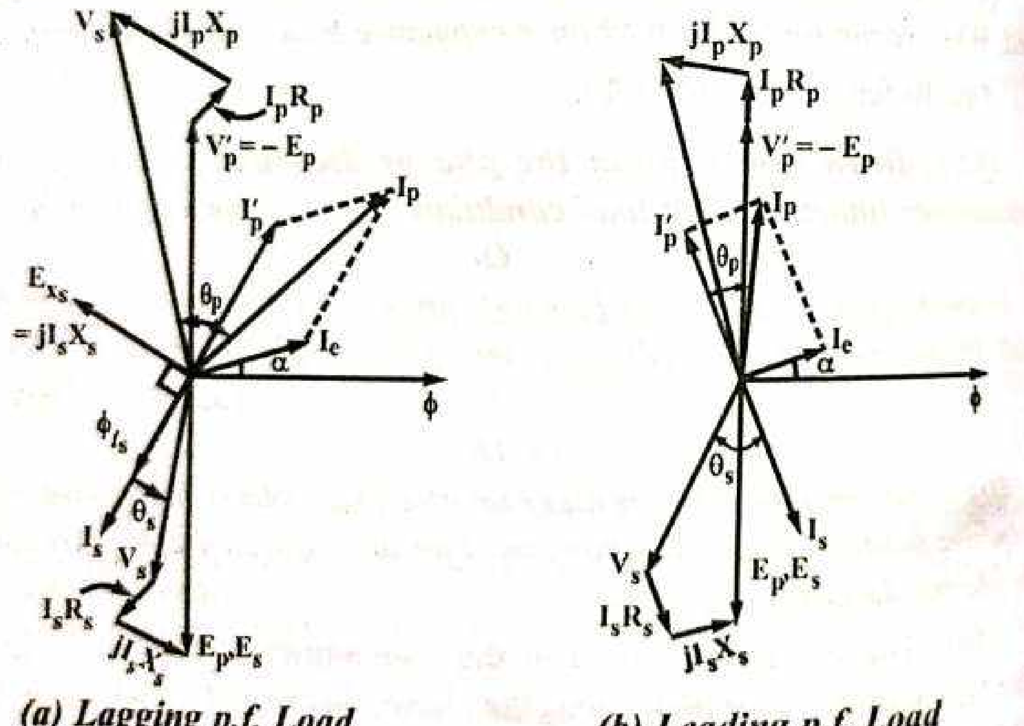
Fig. 3.33 Transformer under Load

When switch S is closed, secondary current I_s starts flowing from terminal n to the load. Assume the load to have a lagging power factor so that I_s lags secondary load voltage V_s by an angle θ_s. At first V_s is drawn with I_s lagging V_s by the secondary p.f. angle θ_s, fig. 3.34 (a). The secondary resistance drop is accounted for, by drawing $R_s I_s$ parallel to I_s. The secondary M.M.F. $I_s N_s$ gives rise to leakage flux ϕ_{l_s} which links only the secondary and not the primary. The flux ϕ_{l_s} is called the secondary leakage flux and is in phase with I_s, for the same reason that ϕ_{l_p} is in phase with I_e. The secondary leakage flux induces e.m.f. E_{x_s} in the secondary winding, lagging ϕ_{l_s} by 90°. The secondary no load voltage E_s must have a component equal and opposite to $-jX_S\bar{I}_S$. Thus the phasor sum of $\bar{V}_s, \bar{I}_s R_s$ and $j\bar{I}_S X_S$ gives the secondary induced e.m.f. E_s as shown in fig. 3.34 (a).

The voltage equation for the secondary circuit can now be written as

$$\bar{E}_S = \bar{V}_s + \bar{I}_s(R_s + jX_s) = \bar{V}_s + \bar{I}_s Z_s \quad ...(i)$$

where, Z_s is the secondary leakage impedance of the transformer.



(a) Lagging p.f. Load *(b) Leading p.f. Load*

Fig. 3.34 Transformer Phasor Diagram

Further the mutual flux ϕ is drawn leading E_s by 90° and exciting current I_e is drawn leading ϕ by the hysteretic angle α. Note that the phasor V_s has purposely been taken to the left of vertical line, so that E_s is vertically downward and the mutual flux ϕ is horizontal.

The component of the primary current which neutralises the demagnetizing effect of I_s is $I'_p(I'_p N_p = I_s N_s)$ and is drawn opposite to I_s. The phasor sum of I'_p and I_e gives the total primary current I_p taken from the supply mains. The primary leakage impedance drop is $\bar{I}_p(R_p + jX_p)$. The voltage equation for

the primary circuit under load can be written as

$$\bar{V}_p = \bar{V}_p' + \bar{I}_p(R_p + jX_p) = \bar{V}_p' + \bar{I}_p Z_p \quad ...(ii)$$

where, Z_p is the primary leakage impedance of the transformer. Note that the angle θ_p between V_p and I_p is the primary power factor angle under load.

If the secondary load current I_s leads the voltage V_s such that the load p.f. is leading, then the phasor diagram for the transformer is as shown in fig. 3.34 (b). The entire procedure for drawing the phasor diagram is the same as explained for fig. 3.34 (a).

The development of transformer phasor diagram gives a better physical picture of what happens in the primary and secondary windings of a transformer and its core.

NUMERICAL PROBLEMS

Prob. 7. A single phase transformer has 350 primary and 1050 secondary turns. The net cross-sectional area of the core is 55 cm². If the primary winding be connected to a 400 V, 50 Hz single phase supply, calculate –

(i) Maximum value of flux density in the core

(ii) Voltage induced in the secondary winding.

(R.G.P.V., Dec. 2016)

Sol. Given, $N_p = 350, N_s = 1050$

$$A = 55 \text{ cm}^2 = 55 \times 10^{-4} \text{ m}^2$$

$$E_p = 400 \text{ V}, f = 50 \text{ Hz.}$$

(i) Induced voltage in primary winding,

$$E_p = 4.44 \, f B_m A N_p$$

$$400 = 4.44 \times 50 \times B_m \times 55 \times 10^{-4} \times 350$$

Maximum value of flux density in the core is,

$$B_m = \frac{400}{4.44 \times 50 \times 55 \times 10^{-4} \times 350} = \mathbf{0.936 \ Wb/m^2} \quad \textbf{Ans.}$$

(ii) Voltage induced in the secondary winding,

$$E_s = E_p \times \frac{N_s}{N_p} = 400 \times \frac{1050}{350} = \mathbf{1200 \ volt} \quad \textbf{Ans.}$$

Prob. 8. A single phase 50 Hz, 250 V (primary) transformer has 80 turns on primary and 280 turns on secondary side. The area of core is 200 cm². Calculate –

(i) Maximum flux density on core

(ii) Induced e.m.f. on secondary side.

(R.G.P.V., Dec. 2015)

Sol. Given, $E_p = 250$ V, f = 50 Hz

$N_p = 80, N_s = 280$

$A = 200 \text{ cm}^2 = 200 \times 10^{-4} \text{ m}^2$

(i) Induced e.m.f. in primary is given by

$$E_p = 4.44 \, f B_m A N_p$$

$$250 = 4.44 \times 50 \times B_m \times 200 \times 10^{-4} \times 80$$

Maximum flux density in core,

$$B_m = \frac{250}{4.44 \times 50 \times 200 \times 10^{-4} \times 80} = \mathbf{0.704 \ Wb/m^2} \quad \textbf{Ans.}$$

(ii) Induced e.m.f. on secondary side,

$$E_s = E_p \times \frac{N_s}{N_p} = 250 \times \frac{280}{80} = \mathbf{875 \ V} \quad \textbf{Ans.}$$

Prob.9. A single phase transformer is connected across 200 V, 50 Hz supply. Number of turns in primary is 500 while in secondary is 1000. The net cross sectional area of the core is 80 cm², calculate –

(i) Transformation ratio
(ii) Maximum flux density in core
(iii) E.M.F. induced in secondary winding.

(R.G.P.V., Dec. 2013)

Sol. Given, $E_p = 200$ V, f = 50 Hz

$N_p = 500, N_s = 1000$

$A = 80 \text{ cm}^2 = 80 \times 10^{-4} \text{ m}^2$

(i) Transformation ratio –

$$K = \frac{N_s}{N_p} = \frac{1000}{500} = \mathbf{2} \quad \textbf{Ans.}$$

(ii) Induced e.m.f. in primary is given by

$$E_p = 4.44 \, f B_m A N_p$$

$$200 = 4.44 \times 50 \times B_m \times 80 \times 10^{-4} \times 500$$

Maximum flux density in core,

$$B_m = \frac{200}{4.44 \times 50 \times 80 \times 10^{-4} \times 500} = \mathbf{0.225 \ Wb/m^2} \quad \textbf{Ans.}$$

(iii) E.m.f. induced in secondary winding,

$$E_s = E_p \times \frac{N_s}{N_p} = 200 \times \frac{1000}{500} = \mathbf{400 \ volt} \quad \textbf{Ans.}$$

Prob.10. A single phase transformer is connected to a 230 V, 50 Hz supply. The net cross sectional area of the core is 60 cm². The number of turns in the primary is 500 and in the secondary 100. Determine –

(i) Transformation ratio
(ii) Maximum value of flux denity in the core
(iii) E.M.F. induced in secondary winding.

(R.G.P.V., June 2017)

Sol. Students solved yourself, same as prob.9.

***Prob.11.** A 10 kVA transformer has 200 turns on the primary and 40 turns on the secondary winding. The primary is connected to 1000 volts, 50 Hz supply. Calculate the full load secondary current, secondary voltage and maximum flux in the core.* *(R.G.P.V., May 2018)*

Sol. Given, $N_p = 200, N_s = 40, E_p = 1000$ V, $f = 50$ Hz

At full load, $$I_p = \frac{10 \times 10^3}{1000} = 10 \text{ A}$$

Now, $$\frac{I_p}{I_s} = \frac{E_s}{E_p} = \frac{N_s}{N_p}$$

Secondary current, $$I_s = \frac{N_p}{N_s} \times I_p = \frac{200}{40} \times 10 = \mathbf{50\ A} \qquad \textbf{Ans.}$$

Secondary voltage, $$E_s = \frac{N_s}{N_p} \times E_p = \frac{40}{200} \times 1000 = \mathbf{200\ V} \qquad \textbf{Ans.}$$

Using relation, $E_p = 4.44\, N_p\, f\, \phi_m$

Maximum flux in the core is given by

$$\phi_m = \frac{E_p}{4.44 N_p f} = \frac{1000}{4.44 \times 200 \times 50} = \mathbf{0.0225\ Wb} \textbf{ Ans.}$$

VOLTAGE REGULATION, LOSSES AND EFFICIENCY, OPEN CIRCUIT AND SHORT CIRCUIT TEST

***Q.52.** Define regulation of transformer. Derive the formula for its approximate voltage regulation. Draw phasor diagram. (R.G.P.V., June 2009)*

Or

State voltage regulation of a transformer. *(R.G.P.V., Dec. 2008)*

Ans. The voltage regulation of a transformer is defined as the change in the secondary terminal voltage between no load to full load conditions, when full load rated voltage reduced to zero with primary voltage held constant.

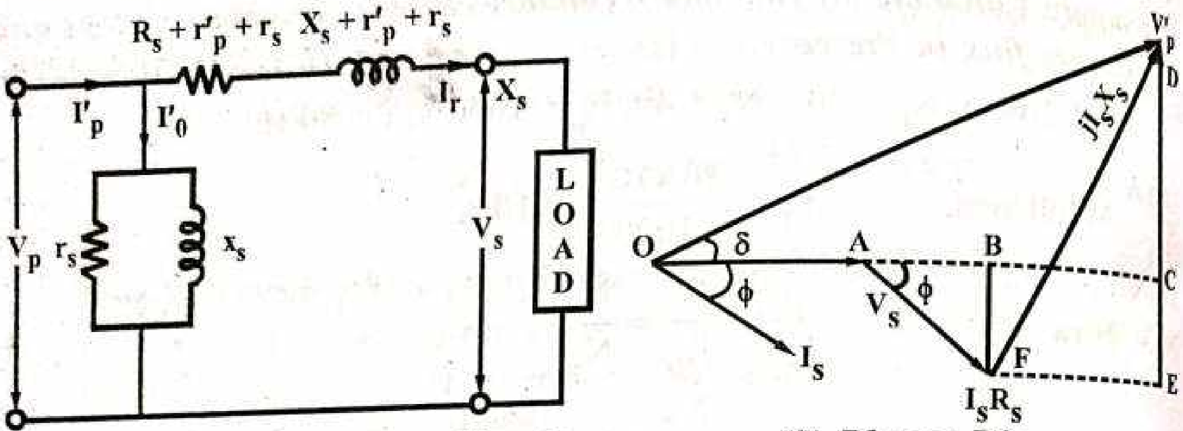
$\therefore$ % Voltage regulation,

$$= \frac{\text{No load secondary voltage} - \text{Full load secondary voltage}}{\text{No load secondary voltage}} \times 100$$

or $\quad$ % Voltage regulation $= \dfrac{E_s - V_s}{E_s} \times 100$

where, E_s = Secondary no load voltage
V_s = Secondary full load voltage.

The voltage regulation of a transformer can be obtained from its approximate equivalent circuit referred to primary or secondary and the associated phasor diagram.



(a) Approximate Equivalent Circuit Referred to Secondary Side $\qquad$ *(b) Phasor Diagram*

Fig. 3.35

As the voltage drop across X and R is very small the angle δ is nearly equal to zero, and we may assume that,

$$OD = OC = OA + AB + BC$$

$$\therefore \quad V_p' = V_s + I_sR_s\cos\phi + I_sX_s\sin\phi$$

$$V_p' - V_s = I_sR_s\cos\phi + I_sX_s\sin\phi$$

$$\frac{V_p' - V_s}{V_s} = \frac{I_s}{V_s}(R_s\cos\phi + X_s\sin\phi)$$

But, $\quad \dfrac{V_p' - V_s}{V_s}$ = Voltage regulation

$$\therefore \quad \text{Voltage regulation} = \frac{I_s}{V_s}(R_s\cos\phi + X_s\sin\phi)$$

where, I_s = Rated secondary current, V_s = Rated secondary voltage.

Hence,

$$\text{Voltage regulation} = \frac{I_sR_s}{V_s}.\cos\phi + \frac{I_sX_s}{V_s}\sin\phi \quad ...(i)$$

$$= R_{pu}\cos\phi + X_{pu}\sin\phi$$

where, $\quad R_{pu} = \dfrac{I_sR_s}{V_s}$ = Per unit resistance

$$X_{pu} = \frac{I_s X_s}{V_s} = \text{Per unit reactance}$$

and

Similarly for leading power factor,

$$\text{Voltage regulation} = R_{pu}\cos\phi - X_{pu}\sin\phi \quad ...(ii)$$

Thus, from the equations (i) and (ii), we see that when power factor increases, voltage regulation is also increases. It is maximum for lagging power factor and minimum for leading power factor.

Q.53. Why cores are laminated in transformers ? How quality of the core affects the performance of a transformer ? **(R.G.P.V., March/April 2010)**

Or

Give reasons why cores of transformer is laminated with laminated sheets ? **(R.G.P.V., June 2012)**

Ans. The transformer consists of two coils having mutual inductance and a laminated steel core. The two coils are insulated from each other and the steel core. Other necessary parts are – some suitable container for assembled core and windings; a suitable medium for insulating the core and its windings from its container, suitable bushings for insulating and bringing out the terminals of windings from the tank.

In all types of transformers, the core is constructed of transformer sheet steel laminations assembled to provide a continuous magnetic path with a minimum of air-gap included. The steel used is of high silicon content, sometimes heat treated to produce a high permeability and a low hysteresis loss at the usual operating flux densities.

The effect of laminations is to confined eddy currents to highly elliptical paths that enclose little flux, and so reduce their magnitude. Thinner laminations reduce losses, but are more laborious and expensive to construct. Hence eddy current loss is minimized by laminating the core.

The thickness of laminations varies from 0.35 mm for a frequency of 50 Hz to 0.5 mm for a frequency of 25 Hz. The core laminations (in the form of strips) are joined as shown in fig. 3.36. It is seen that the joints in the alternate layers are staggered in order to avoid the presence of narrow gaps right through the cross-section of the core. Such staggered joints are said to be 'imbricated'.

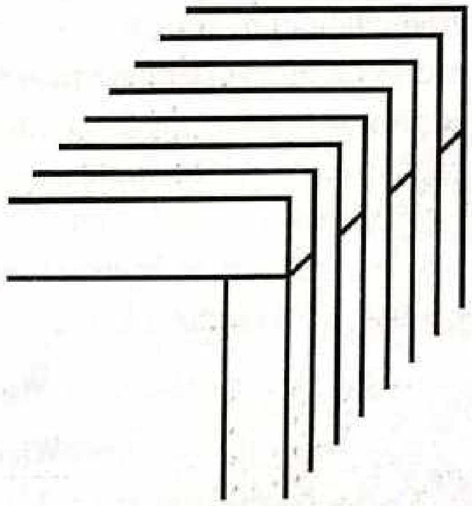


Fig. 3.36 Laminated Core

Q.54. Give reasons why rating of transformer is specified in kVA and not in kW. **(R.G.P.V., June 2012)**

Ans. Since rated transformer output is limited by heating and hence by

the losses in the transformer. There are two types of losses in a transformer, i.e. core loss and copper (I^2R) loss. The core loss depends on transformer voltage and copper loss depends on the transformer current. As these losses depend on transformer voltage (V) and current (I) and are almost unaffected by the load power factor. Therefore the transformer rated output is expressed in VA (V × I) or in kVA and not in kW.

Q.55. What are the various losses in a transformer ? How can they be minimized ? ***(R.G.P.V., March/April 2010)***

Or

Give reasons why core losses are called iron losses ? (R.G.P.V., June 2012)

Or

Describe in detail the losses in transformer. ***(R.G.P.V., Dec. 2016)***

Ans. There are mainly two types of losses occur under loaded conditions in a transformer viz

(i) Core losses (ii) Copper losses.

(i) Core or Iron Loss – Core losses occur in the magnetic core of the transformer. It includes hysteresis and eddy current losses. Core loss is found from the open circuit test.

Core losses are constant for a particular transformer because core flux is practically independent of load. It varies in a narrow range of 1 to 3% from no load to full load.

When a ferromagnetic material is subjected to cyclic changes of magnetisation then during one complete cycle the domains change the direction of their orientation as the applied magnetising force **H** changes its direction. Work is done in changing the direction of the domain which leads to the production of heat within the material and is referred to as hysteresis loss. The energy required in taking a material through one complete cycle of magnetisation is proportional to the area enclosed by the hysteresis loop. If **H** is brought back to zero and the cycle repeated at less than saturation, a similar hysteresis loop of smaller area is obtained.

For calculating hysteresis loss, an empirical formula is used which is also known as "Steinmetz law".

So, $$W_h = \eta B_{max}^n \, f V \text{ watts}$$

or $$\frac{W_h}{V} = \eta B_{max}^n \, f \text{ watts/m}^3$$

where, η = Constant and its value depends upon the nature of the magnetic material

B_{max} = Maximum value of flux density in Wb/m^2 or Tesla

n = Power whose value depends upon the range of flux density employed

f = Frequency in Hz

V = Volume of the magnetic material in m^3.

and

When alternating magnetic field is applied to a magnetic material, eddy current is induced in the magnetic material. This is because the change in flux density induces internal electromotive force in the core of electromagnet. Due to this e.m.f. the small current setup, which circulates locally in the core is called eddy current. This current causes loss of energy (i^2R) in the material and is generally referred to as eddy current losses. This loss of energy also results in heating up of the material.

Eddy current losses can be calculated by the formula given below –

$$W_e = k\mathbf{B}_{max}^2 f^2 t^2 V \text{ watts}$$

$$\frac{W_e}{V} = k\mathbf{B}_{max}^2 f^2 t^2 \text{ watts/m}^3$$

and

From the above relation it is clear that eddy current loss is proportional to the square of the frequency, square of the material thickness, square of the maximum flux density, volume of the magnetic material. Eddy current losses are inversely proportional to the resistivity of the material. That is why magnetic cores to be used in alternating magnetic fields, instead of being solid, are generally build up of thin sheets of steel (called lamination) separated from each other by a thin film of insulation. This helps in reducing the eddy current losses.

$\therefore$ Core losses = $W_c = W_i = W_h + W_e$

(Core or iron loss) $W_i = \eta B_m^{1.6} f V + p B_m^2 f^2 t^2$

Hence core loss increases with increase in voltage and decreases with increase in frequency, but these losses are independent of load.

(ii) Copper Losses (I^2R - Losses) – This loss is occur due to ohmic resistance of the transformer winding. It is equal to $\left(I_p^2 R_p + I_s^2 R_s\right)$.

Copper losses are variable losses, depend upon load on transformer, as the load increases, current in primary and secondary windings also increases and hence copper losses increases in transformer. Copper losses are found from the short circuit test on the transformer.

Copper losses decreases when voltage is increased, but these losses are independent of frequency, these losses increases with load.

Methods for Reducing Losses in Transformer –

(i) Core loss in a transformer can be reduced by using steel of high silicon content for the core and by using thin laminations.

(ii) Copper loss in a transformer can be reduced or minimized by using proper dimension and material of the conductor. The cooling should be proper because resistance depends on temperature.

The following two losses are also present in transformers (a) stray load loss and (b) dielectric loss.

These losses are very small and are, therefore neglected.

Q.56. Derive an approximate equivalent circuit of transformer and discuss the losses in transformer. **(R.G.P.V., Dec. 2017)**

Ans. Refer the ans. of Q.45 and Q.55.

Q.57. Explain the following w.r.t. transformer –
(i) Losses (ii) Voltage regulation. **(R.G.P.V., June 2012)**

Ans. (i) Losses – Refer the ans. of Q.55.

(ii) Voltage Regulation – Refer the ans. of Q.52.

Q.58. Give the reason of eddy current loss in transformer core. **(R.G.P.V., Dec. 2014)**

Ans. Since the flux in a transformer core is alternating, it links with the magnetic material of the core. This induces e.m.f. in the core and circulates eddy currents. Power is required to maintain these eddy currents. This power is dissipated in the form of heat and is known as eddy current loss $(P_e = K_e V f^2 t^2 B_m^2)$. This loss can be minimized by making the core of the thin laminations.

Q.59. State Ampere's circuit law. What is M.M.F. and flux density. How ampere circuital law is used in magnetic circuit analysis. Explain hysteresis and eddy current losses. **(R.G.P.V., Dec. 2012)**

Ans. **Ampere's Circuital Law** – It states that the line integral of **H** along any closed path is exactly equal to the direct current enclosed by the path. Mathematically,

$$\oint \mathbf{H}.\,dl = I$$

The positive current is taken in the direction of advancing right handed screw turned in the direction in which the closed path is traversed. It is shown in fig. 3.37 (a). This law is analogous to Gauss's law and with the help of this law we can determine the magnetic field around a current carrying conductor.

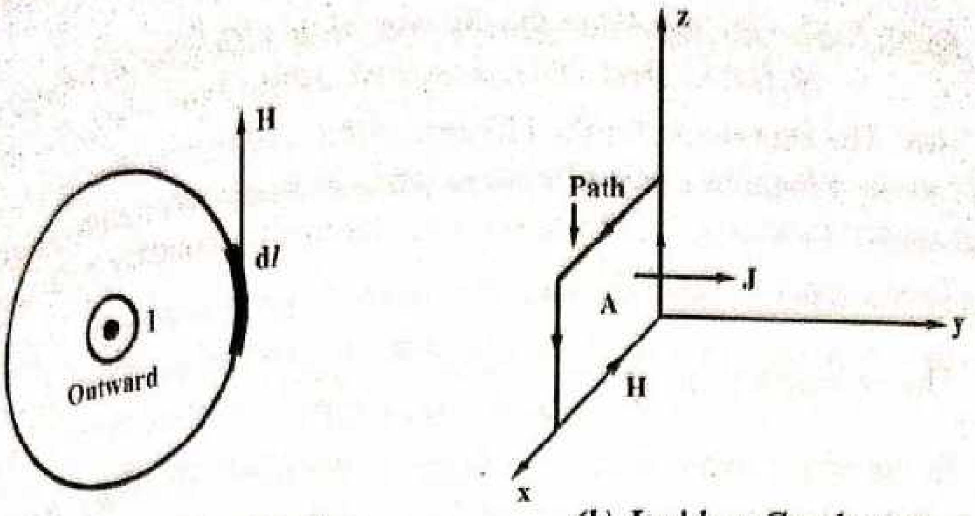
We know that field intensity at a point distance r from a long straight current carrying conductor is given by,

$$\mathbf{H} = \frac{I}{2\pi r}\mathbf{a}_\phi$$

When we take integral of H around a closed path, then

$$\oint \mathbf{H}.\,dl = \frac{I}{2\pi r}\int ds = \frac{I}{2\pi r} \times 2\pi r$$

$$\therefore \quad \oint \mathbf{H}.\,dl = I$$



(a) Current Enclosed *(b) Inside a Conductor*

Fig. 3.37 Explanation for Ampere's Circuital Law

With the help of this law we can determine **H** when the two conditions met –

(i) **H** is either tangential or normal to the path at each point on the closed path.

(ii) Where **H** is tangential, it has same value at all points of the path.

M.M.F. and Flux Density – Refer the ans. of Q.5 (i) and Q.5 (vi).

Hysteresis and Eddy Current Losses – Refer the ans. of Q.55.

Q.60. Discuss the effect of hysteresis and eddy current in magnetic circuit. ***(R.G.P.V., June 2017)***

Ans. Refer the ans. of Q.55.

Q.61. Define voltage regulation and efficiency of a transformer. Give the formula also. ***(R.G.P.V., Dec. 2014)***

Ans. **Voltage Regulation** – Refer the ans. of Q.52.

Transformer Efficiency – The efficiency of a transformer is defined as the ratio of output power to input power. Thus

$$\text{Efficiency, } \eta = \frac{\text{Output power}}{\text{Input power}} = \frac{V_2 I_2 \cos\theta_2}{V_2 I_2 \cos\theta_2 + P_c + I_2^2 R_{e2}} \quad ...(i)$$

where, P_c = Total core loss, $I_2^2 R_{e2}$ = Total ohmic losses

$\cos\theta_2$ = Load power factor, $V_2 I_2$ = Output VA.

We know that, stray load losses and dielectric losses are small and have been ignored. The efficiency can also be expressed as follows –

$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

$$= \frac{\text{Input power} - \text{Losses}}{\text{Input power}} = 1 - \frac{\text{Losses}}{\text{Input power}} \quad ...(ii)$$

Q.62. Derive the condition for the maximum efficiency of transformer.
(R.G.P.V., Dec. 2003, Jan./Feb. 2006, June 2007, Dec. 2011)

Ans. The expression for the efficiency of a transformer can be modified by expressing the total copper losses in terms of secondary current I_s and the equivalent resistance of the transformer in terms of secondary winding.

Total copper losses = $I_s^2 \overline{R}_s$

$$\text{Thus efficiency, } \eta = \frac{V_s I_s \cos\phi}{V_s I_s \cos\phi + W_c + I_s^2 R_s}$$

In the above expression for efficiency, the terminal voltage across the secondary is approximately constant for a particular transformer. Thus for a load of given power factor, the efficiency will be maximum, when the denominator is minimum

$$\frac{d}{dI_s}\left(V_s \cos\phi + \frac{W_c}{I_s} + I_s \overline{R}_s\right) = 0 \quad \text{or} - \frac{W_c}{I_s^2} + \overline{R}_s = 0$$

Hence $I_s^2 \overline{R}_c = W_c$

Total copper losses = Constant losses.

Hence, the efficiency of the transformer is maximum at a load that makes the total copper losses equal to the constant losses.

Q.63. Specify the following w.r.t. transformer –
(i) All day efficiency (ii) Losses in the transformer.
(R.G.P.V., June 2013)

Ans. (i) All Day Efficiency – The transformers used for distribution purpose are energised for all the 24-hours a day of their primaries, although their secondaries supply little or no load much of the time during the day except during the house lighting period. It means that the core loss occurs throughout the day whereas the copper loss occur only when the transformer is loaded. Such performance is compared on the basis of energy consumed during a day or 24-hours. Therefore, we can write the expression as follows –

$$\therefore \quad \text{All day efficiency} = \frac{\text{Output in kWh (in 24-hours)}}{\text{Input in kWh}}$$

All day efficiency is also known as 'Operational efficiency'. This efficiency is always less than the commercial efficiency of a transformer.

The ordinary or commercial efficiency which is given by the ratio of output power to input power

$$\text{i.e., commercial efficiency } \eta = \frac{\text{Output power}}{\text{Input power}}$$

(ii) Losses in the Transformer – Refer the ans. of Q.55.

Q.64. What do you mean by transformer on no-load and load conditions ? Explain with phasor diagram.

Or

State and explain no-load current with this components.

(R.G.P.V., Dec. 2008, June 2016)

Ans. **Transformer on No-load** – When the transformer is on no-load, the current in the secondary winding is zero, i.e., they are open circuited. The primary current under no-load condition consisting of two components.

(i) ***An active or power component*** I_w because it mainly supplies the iron loss and small quantity of primary Cu loss.

(ii) ***A reactive or magnetizing component*** I_m, its function is to sustain the alternating flux in the core.

Phasor diagram for no-load conditions is shown in fig. 3.38.

Active component of current is in phase with supply voltage i.e., V_p and

$I_w = I_0 \cos \phi_0$

where, I_0 is no-load current and $\cos \phi$ is primary power factor under no-load condition.

Magnetizing or reactive component is in quadrature with V_p and in phase with flux i.e.,

$$I_m = I_0 \sin \phi_0$$

Hence, the sum of phasor I_m and I_w gives the no-load current, I_0

$$\therefore \qquad I_0 = \sqrt{I_m^2 + I_w^2}$$

and power factor at no-load, $\cos \phi_0 = \dfrac{I_w}{I_0}$

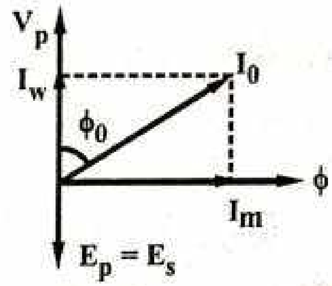


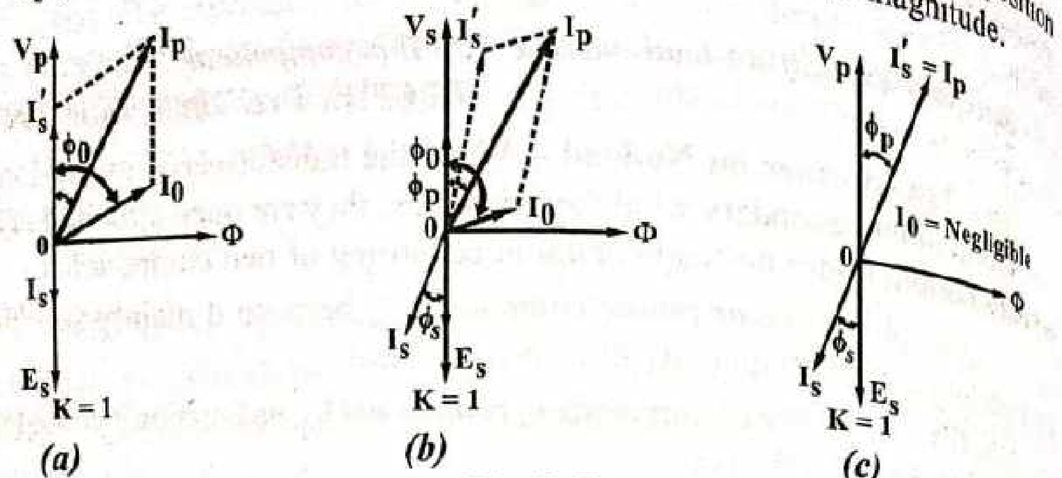
Fig. 3.38 Phasor Diagram on No-load

As the magnitude of I_w is quite small compared to I_0, the power factor of the transformer at no-load is very low.

Transformer on Load – When the secondary winding is loaded, the current (I_s) in the secondary winding is set-up. The magnitude and phase of secondary current (I_s) with respect to the secondary voltage (V_s) is determined by the characteristics of the load. Secondary current is in phase with secondary voltage if load is non-inductive, it lags if load is inductive and it leads if load is capacitive.

Secondary current sets up its own M.M.F. = N_sI_s (called demagnetizing ampere-turns), consequently flux Φ_s. The opposing secondary flux Φ_s weakens the primary flux Φ_p momentarily, hence primary back e.m.f. E_p tends to be reduced. Let the additional primary current be I_s', which is known as ***load component of the primary current***. This current is anti-phase with I_s and an

additional primary M.M.F. $N_p I_s'$ sets up its own flux Φ_s' which is in opposition to Φ_s (but is in the same direction as ϕ) and is equal to it in magnitude.



(a) *(b)* *(c)*

Fig. 3.39

Hence, the two opposing flux in primary and secondary windings cancel to each other. It is concluded, whatever the load conditions, ***the net flux passing through the core is approximately the same as at no-load***. Hence due to constancy of core flux at all loads, the core loss is also practically the same under all load conditions.

As $$\Phi_s = \Phi_s'$$

$\therefore$ $$N_s I_s = N_p I_s'$$

$\therefore$ $$I_s' = \frac{N_s}{N_p} \times I_s = K I_s$$

When transformer is on load, the primary winding has two currents in it; one is I_0 and other is I_s' which is anti-phase with I_s and K times in magnitude. The total primary current is the vector sum of I_0 and I_s'.

In fig. 3.39 (a), I_s is secondary current in phase with E_s. It causes primary current I_s' which is anti-phase and equal in magnitude (K = 1). Total primary current I_p is the vector sum of I_0 and I_s' and lags behind V_p by an angle ϕ_p.

In fig. 3.39 (b) vectors are drawn for an inductive load. I_s lags E_s by an angle ϕ_s. Current I_s' is again anti-phase with I_s and equal to it in magnitude. The I_p is the vector sum of I_s' and I_0 and lags behind V_p by ϕ_p. The ϕ_p is slightly greater than ϕ_s. But if we neglect I_0 as compared to I_s' as in fig. 3.39(c) then $\phi_p = \phi_s$. Moreover, under this assumption

$$N_p I_s' = N_p I_p = N_s I_s$$

$\therefore$ $$\frac{I_s'}{I_s} = \frac{I_p}{I_s} = \frac{N_s}{N_p} = K$$

or $$I_p = K I_s$$

It shows that under full load conditions the ratio of primary and secondary currents is constant. The flux linking both the winding of transformer is taken as the reference phasor.

Q.65. Explain open circuit test and short circuit test of a single phase transformer and give their significance. ***(R.G.P.V., June 2008, Dec. 2010)***

Or

How transformer is used for impedance transformation ? Explain the no load test used for the transformer parameter determination.

(R.G.P.V., Dec. 2012)

Or

Explain with circuit diagrams, the open circuit test and short circuit test to be conducted on 1-ϕ transformer. ***(R.G.P.V., Dec. 2015)***

Or

Explain lab method to perform open circuit and short circuit test on single phase transformer. ***(R.G.P.V., Dec. 2016)***

Or

Write short note on O.C. and S.C. test in transformer.

(R.G.P.V., Nov. 2018)

Or

Explain the O.C. and S.C. test of a transformer.

[R.G.P.V., Nov. 2018(O)]

Ans. The purpose of performing open circuit test is to calculate iron losses or core losses and through short circuit test we can find out copper losses. Hence the efficiency of transformer can be calculated more accurately by these two tests.

Open Circuit Test or No Load Test – High voltage winding of the transformer is left open and low voltage winding is connected to its supply of normal voltage and frequency. A wattmeter W, voltmeter V and an ammeter A are connected in the low voltage winding as shown in fig. 3.40.

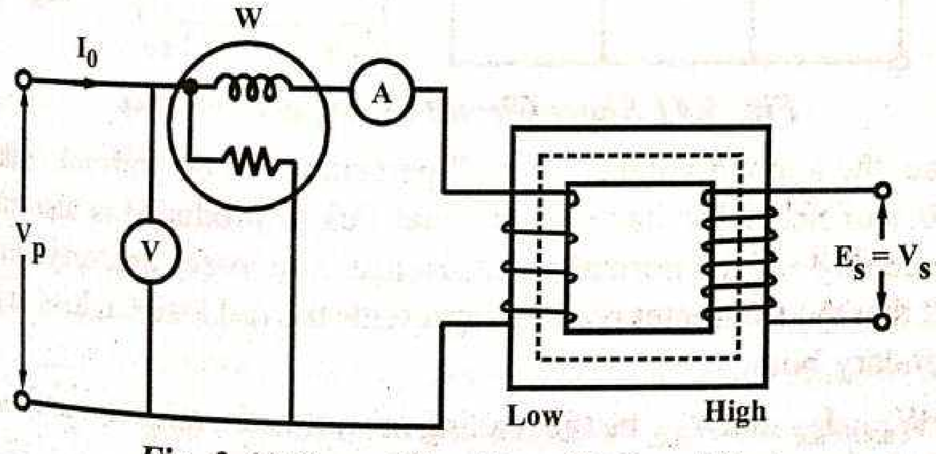


Fig. 3.40 Open Circuit or No Load Test

With normal voltage applied to the primary or low voltage winding, the flux will be set up in the core and hence iron losses will occur, which are

recorded by the wattmeter. As the primary no-load current I_0 is small (usually 2% to 10% of rated load current) Cu loss is negligible in primary and nil in secondary. Hence the wattmeter reading represents practically the core loss under no load conditions.

Open circuit parameters can be calculated from wattmeter reading as follows –

If W is wattmeter reading, then

$$W = V_p I_0 \cos \phi_0$$

$$\cos \phi_0 = W/V_p I_0$$

$$\because \quad I_m = I_0 \sin \phi_0 \quad \text{and} \quad I_w = I_0 \cos \phi_0$$

$$\therefore \quad X_0 = V_p/I_m \quad \text{and} \quad R_0 = V_p/I_w$$

Thus, open circuit test gives the following information –

(i) No load loss or core loss

(ii) The shunt branch parameter of equivalent circuit, i.e., R_0 and X_0.

Short Circuit Test or Impedance Test – Low voltage winding of the transformer is solidly short circuited with a thick conductor. High voltage winding connected to supply and supply voltage is increased slowly until full load current flows in this winding and consequently in low voltage winding.

A wattmeter W, a voltmeter V and an ammeter A are connected to supply side as shown in fig. 3.41.

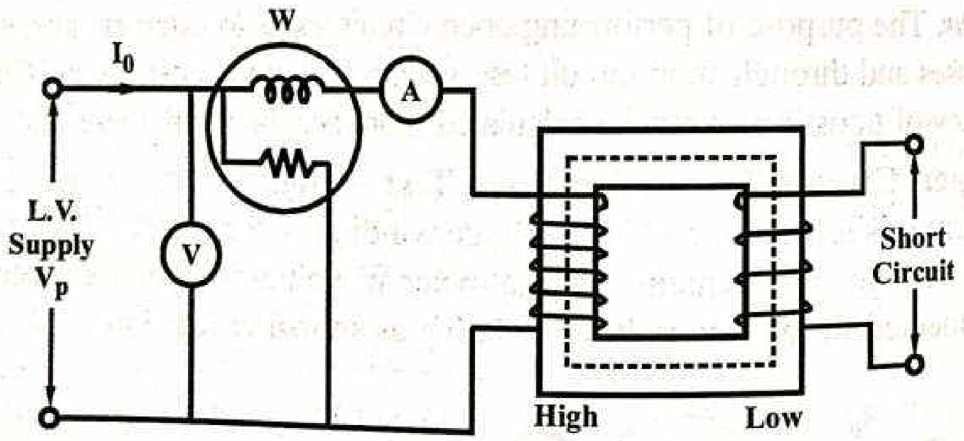


Fig. 3.41 Short Circuit or Impedance Test

Since, the applied voltage is small percentage of the normal voltage, i.e. 5% to 10% of normal voltage, the mutual flux Φ produced is also in a very small percentage of the normal value. Hence core losses are very small with the result that the wattmeter reading represents the full load Cu loss in primary and secondary both.

Let $W_{s.c.}$, $I_{s.c.}$ and $V_{s.c.}$ be the reading of wattmeter, ammeter and voltmeter respectively.

Then, $$W_{s.c.} = (I_{s.c.})^2 R_{eq} \quad \text{or} \quad R_{eq} = \frac{W_{s.c.}}{(I_{s.c.})^2}$$

$$Z_{eq} = \frac{V_{s.c.}}{I_{s.c.}}$$

Also,

$$\therefore \quad X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$$

Thus, the short circuit test gives the following information as –

(i) Copper loss at full load, (also called ohmic losses).

(ii) Equivalent impedance, leakage reactance and total resistance of the transformer as referred to primary.

(iii) The total voltage drop in the transformer as referred to primary or secondary can be calculated and hence regulation of the transformer determined.

Q.66. How will you determine the transformer losses in the laboratory ?
(R.G.P.V., June 2013)

Or

What quantities can be find out using open circuit test on 1-ϕ transformer ? Explain how you can perform open circuit test on 1-ϕ transformer in the laboratory ? ***(R.G.P.V., Dec. 2013)***

Ans. Refer the ans. of Q.65.

Q.67. Give reasons why cooling is required in transformer ?
(R.G.P.V., June 2012)

Ans. Under operating conditions, either transformer on-load or no-load, iron and Cu losses take place in it,causing a lot of heat inside the transformer. If this heat is not dissipated to the atmosphere, the temperature of various parts of the transformer will go beyond the prescribed limits which may cause of the insulation failure. Hence transformer requires an elaborate cooling system.

Generally following cooling methods are used –

(i) Oil-immersed (Filled) Self Cooled – The dissipation of heat by the transformer tank to the atmosphere is by natural process. Hot oil flows (known as 'insulating oil') upwards through ducts and then flows down along the inner walls of the oil-tight steel tank provided with steel cover. The tank surface dissipates heat to the atmosphere.

This method of cooling is used in distribution transformers.

(ii) Oil-immersed Forced Air Cooled – The transformer is not immersed in oil, but is housed in a thin-sheet metal box open at both ends through which air is blown from the bottom to the top by means of a blower. For voltages below 25 kV transformers can be built for cooling by means of an air-blast.

(iii) Oil-immersed Water Cooled – In this type of cooling system, the winding and the core are immersed in the oil. It has forced circulation of

oil by a pump. Oil is pumped through the ducts and then through external radiators, which are cooled by fans. The oil pumping equipment adds to the cost, but cooling is more effective.

The largest transformers such as those used with high voltage transmission lines are constructed in this manner.

NUMERICAL PROBLEMS

Prob.12. The O.C. and S.C. tests on a 5 kVA, 230/110 V, 50 Hz transformer gave the following data –

O.C. test (H. V. side) –	*230 V,*	*0.6 A,*	*80 W*
S.C. test (L.V. side) –	*6 V,*	*15 A,*	*20 W*

Calculate percentage efficiency and regulation of a transformer on full load at 0.8 p.f. lagging. ***(R.G.P.V., Dec. 2011)***

Sol. From O.C. test, Iron losses, $P_i = 80$ W

and from S.C. test, Copper losses, $P_c = 20$ W

$$\text{Efficiency, } \eta = \frac{\text{kVA} \times 1000 \times \cos\phi}{\text{kVA} \times 1000 \times \cos\phi + P_i + P_c} \times 100$$

$$= \frac{5 \times 1000 \times 0.8}{5 \times 1000 \times 0.8 + 80 + 20} \times 100 = \mathbf{97.56\%} \ \textbf{Ans.}$$

From S.C. test, $Z_{eH} = \frac{6}{15} = 0.4\ \Omega$

$$R_{eH} = \frac{20}{(15)^2} = 0.089\ \Omega$$

and $X_{eH} = \sqrt{Z_{eH}^2 - R_{eH}^2}$

$$= \sqrt{(0.4)^2 - (0.089)^2} = 0.39\ \Omega$$

Here $\cos\phi = 0.8$, $\sin\phi = \sin\cos^{-1}(0.8)$, $\sin\phi = 0.6$.

$$\text{Drop} = I_s R_{eH} \cos\phi + I_s X_{eH} \sin\phi$$

$$= 15 \times 0.089 \times 0.8 + 15 \times 0.39 \times 0.6 = 4.578 \text{ V}$$

$$\text{Percentage regulation} = \frac{4.578 \times 100}{230} = \mathbf{1.99\% \approx 2\%} \quad \textbf{Ans.}$$

Prob.13. The O.C. and S.C. test conducted on 230/460 V transformer gave following data –

O.C. test (LV side) = 230 V; 1.2 A;85 W

S.C. test (HV side) = 30 V; 14 A; 105 W

Determine the circuit constant. ***(R.G.P.V., Dec. 2016)***

***Sol.* Open-circuit Test –**

$V_1 = 230$ V, $I_0 = 1.2$ A, $P_i = 85$ W, $P_i = V_1 I_0 \cos\phi_0$

$85 = 230 \times 1.2 \cos\phi_0$

or
$$\cos\phi_0 = \frac{85}{230 \times 1.2} = 0.308$$

$$I_w = I_0 \cos\phi_0$$
$$= 1.2 \times 0.308 = 0.3696 \text{ A}$$
$$I_\mu = I_0 \sin\phi_0$$
$$= \sqrt{I_0^2 - I_w^2} = \sqrt{(1.2)^2 - (0.3696)^2} = 1.142 \text{ A}$$
$$R_0 = \frac{V_1}{I_w} = \frac{230}{0.3696} = 622.29\ \Omega$$
$$X_0 = \frac{V_1}{I_\mu} = \frac{230}{1.142} = 201.40\ \Omega$$

Short-circuit Test – As the primary is short circuited, thus all the value refer to the secondary winding. The results of the short-circuit test are given in terms of HV side, whereas the results of the open-circuit test are given in terms of low voltage side. The results obtained in short-circuit test are, thus, converted in terms of the LV side.

$$V_{2sc} = 30 \text{ V},\ P_{cfl} = 105 \text{ W},\ I_{2sc} = 14 \text{ A}$$
$$\frac{T_1}{T_2} = \frac{V_1}{V_2} = \frac{230}{460} = 0.5$$

Voltage applied on the LV side,

$$V_{1sc} = V_{2sc}\frac{T_1}{T_2} = 30 \times \frac{230}{460} = 15\text{V}$$

Primary (LV) full load current,

$$I_{1sc} = I_{2sc}\frac{T_2}{T_1} = 14 \times \frac{460}{230} = 28 \text{ A}$$
$$P_{cfl} = I_{1sc}^2 R_{e_1}$$
$$R_{e_1} = \frac{P_{cfl}}{I_{1sc}^2} = \frac{105}{(28)^2} = 0.1339\ \Omega$$
$$Z_{e_1} = \frac{V_{1sc}}{I_{1sc}} = \frac{15}{28} = 0.5357\ \Omega$$
$$X_{e_1} = \sqrt{Z_{e_1}^2 - R_{e_1}^2} = \sqrt{(0.5357)^2 - (0.1339)^2} = 0.5187\ \Omega$$

The equivalent circuit is illustrated in fig. 3.42.

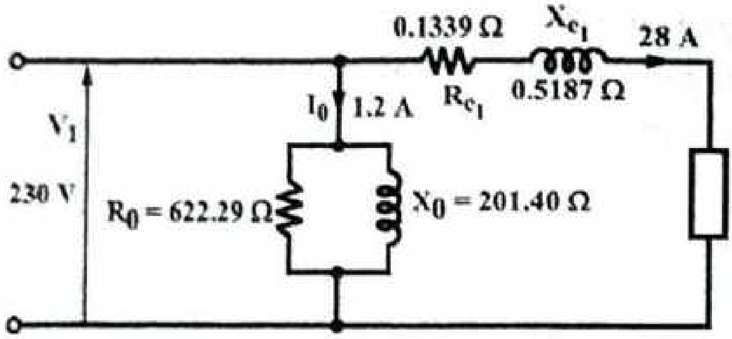


Fig. 3.42 Equivalent Circuit of Prob.13

Prob.14. The results of tests performed on 1-ϕ, 20 kVA, 2200/220 volt 50 Hz. Transformer are as follows –

O.C. test : 220 V, 4.2 A, 148 W

S.C. test : 86 V, 10.5 A, 360 W.

Determine –

The regulation and efficiency at 0.8 p.f. lagging at full load.

(R.G.P.V., Dec. 2014)

Sol. Since during S.C. test instrument have been placed on the primary side

$$Z_{eH} = \frac{86}{10.5} = 8.19\ \Omega$$

$$R_{eH} = \frac{360}{10.5^2} = 3.26\ \Omega,$$

$$X_{eH} = \sqrt{(8.19)^2 - (3.26)^2} = 7.5\ \Omega$$

Full load primary current, $I_1 = \dfrac{20000}{2200} = 9.09$ A

Total approximate voltage drop as referred to primary is $= I_1 (R_{eH} \cos\phi + X_{eH} \sin\phi)$

Here $\cos\phi = 0.8$, $\sin\phi = \sin\cos^{-1}(0.8)$, $\sin\phi = 0.6$

Drop $= 9.09\ (3.26 \times 0.8 + 7.5 \times 0.6) = 64.6$ V

Percentage regulation $= \dfrac{64.6 \times 100}{2200} = 2.94\%$ **Ans.**

From O.C. test, iron loss $P_i = 148$ W and from S.C. test, copper loss $P_c = 360$ W.

$$\text{Efficiency, } \eta = \frac{x \times \text{kVA} \times \cos\phi}{x \times \text{kVA} \times \cos\phi + P_i + P_c} \times 100$$

For full load x = 1,

$$\text{Efficiency, } \eta = \frac{1 \times 20 \times 1000 \times 0.8}{1 \times 20 \times 1000 \times 0.8 + 148 + 360} \times 100$$

$$= 96.92\%$$ **Ans.**

Prob.15. An audio frequency transformer in employed to couple a 60 Ω resistive load to a source of 6 volt in series with the resistance of 2400 Ω.

(i) Determine the transformer turns ratio to ensure the maximum power is transferred to the load.

(ii) Calculate the value of maximum power and corresponding load current and voltage.

(R.G.P.V., Dec. 2012)

Sol. (i) For maximum power transfer, the load resistance of 60 Ω when referred to the primary side must be equal to the source resistance of 2400 Ω.

$$\therefore \quad \frac{R_S}{R_P} = \left(\frac{N_1}{N_2}\right)^2$$

$$\frac{2400}{60} = \left(\frac{N_1}{N_2}\right)^2$$

$$\left(\frac{N_1}{N_2}\right)^2 = 40$$

$$\frac{N_1}{N_2} = \sqrt{40} = \mathbf{6.32} \qquad \textbf{Ans.}$$

(ii) Referring all the values to load side, the equivalent circuit is shown in fig. 3.43.

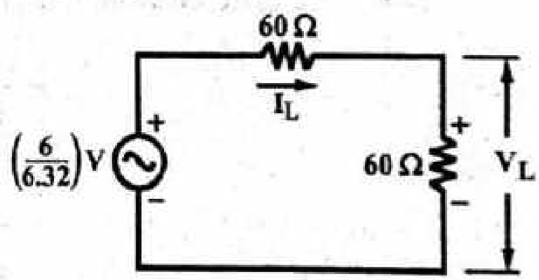


Fig. 3.43

The source voltage on load side is $\left(\frac{6}{6.32}\right)$V and source resistance is 60 Ω.

∴ Load current

$$I_L = \frac{6}{6.32 \times 120} = \mathbf{7.91\ mA} \qquad \textbf{Ans.}$$

Load voltage,

$$V_L = 7.91 \times 10^{-3} \times 60 = \mathbf{0.475\ V} \qquad \textbf{Ans.}$$

Load power

$$P_L = I_L^2 R_L$$

$$= (7.91 \times 10^{-3})^2 \times 60$$

$$= 3.754 \times 10^{-3}\ W = \mathbf{3.754\ mW} \qquad \textbf{Ans.}$$

Prob.16. A single phase transformer rated 570 watt has an efficiency of 95 percent when working at full load and half full load, both at unity p.f. Calculate its efficiency at 75 percent of full load. (R.G.P.V., June 2013)

Sol.

$$\eta_{\text{full-load}} = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + (1)^2 P_c}$$

$$0.95 = \frac{570}{570 + P_i + P_c} \quad ...(i)$$

$$\eta_{\text{half-load}} = \frac{V_2 (I_2/2)\cos\phi}{V_2 (I_2/2)\cos\phi + P_i + (1/2)^2 P_c}$$

$$0.95 = \frac{285}{285 + P_i + \frac{1}{4} P_c} \quad ...(ii)$$

Remaining equation (i) and equation (ii), we get

$$P_i + P_c = 30 \quad ...(iii)$$

$$P_i + \frac{1}{4} P_c = 15 \quad ...(iv)$$

After solving equations (iii) and (iv), we get

$$P_i = 10 \text{ W}$$

$$P_c = 20 \text{ W}$$

Now, the efficiency at 75% full load

$$= \frac{570 \times 0.75}{570 \times 0.75 + P_i + (0.75)^2 P_c}$$

$$= \frac{427.5}{427.5 + 10 + \frac{9}{16} \times 20}$$

$$= 0.953 \text{ p.u or } \mathbf{95.3\%}$$ **Ans.**

Prob.17. A 500 kVA transformer has 90% efficiency at full load and at 70% of full load both at upf (unit p.f.).

(i) Separate out the transformer losses.

(ii) Determine the transformer efficiency at 80% of full load, upf.

(R.G.P.V., June 2014)

Sol. (i) Since we know that

$$\text{Efficiency } (\eta) = \frac{x \times kVA \times \cos\phi}{x \times kVA \times \cos\phi + P_i + x^2 P_c}$$

At full load, $x = 1$

$$\eta = \frac{1 \times 500 \times 1}{(1 \times 500) \times 1 + P_i + 1^2 P_c} = 0.90$$

$$\frac{500}{500 + P_i + P_c} = \frac{0.90}{1}$$

$$P_i + P_c = \frac{500}{0.90} - 500$$

$$55.55 = P_i + P_c \qquad ...(i)$$

Also

$$\eta = \frac{0.6 \times 500 \times 1}{(0.6 \times 500) \times 1 + P_i + (0.6)^2 P_c} = 0.90$$

$$\frac{300}{300 + P_i + 0.36P_c} = 0.90$$

$$P_i + 0.36\ P_c = \frac{300}{0.90} - 300$$

$$33.33 = P_i + 0.36\ P_c \qquad ...(ii)$$

After solving equations (i) and (ii), we get

$P_i =$ **20.83 kW** **Ans.**

$P_c =$ **34.72 kW** **Ans.**

(ii). At 80% of full load, upf

$$\eta = \frac{0.8 \times 500 \times 1}{(0.8 \times 500) \times 1 + 20.83 + (0.8)^2 \times 34.72)} = 0.9028$$

$\eta\% =$ **90.28%** **Ans.**

Prob.18. A 100 kVA, 1000/10,000 V, 50 Hz single phase transformer has an iron loss of 1100 W. The copper loss with 5 A in the high voltage winding is 400 W. Calculate efficiency at 100% normal load for p.f 1.0 and 0.8. ***(R.G.P.V., Dec. 2013)***

Sol. Iron loss = 1100 W

Copper losses with 5 A in high voltage winding = 400 W

High voltage winding full load current,

$$I_s = \frac{100 \times 1000}{10000} = 10\ A$$

Current in the high voltage side at 100% full load

$$= 1 \times 10 = 10\ A$$

Copper losses at 100% full load

$$= \left(\frac{10}{5}\right)^2 \times 400 = 4 \times 400 = 1600\ W$$

Output at 100% full load

$$= 1 \times 100 \times 1000 \times 1 = 100000 \text{ W}$$

Hence, efficiency at 100% load, 1.0 power factor lagging,

$$= \frac{100000 \times 1}{100000 \times 1 + 1100 + 1600} \times 100 = \mathbf{97.4\%\ Ans.}$$

Efficiency at 100% load, 0.8 power factor lagging,

$$= \frac{100000 \times 0.8}{100000 \times 0.8 + 1100 + 1600} \times 100 = \mathbf{96.7\%\ Ans.}$$

●●

UNIT 4

ELECTRICAL MACHINES

CONSTRUCTION, CLASSIFICATION & WORKING PRINCIPLE OF D.C. MACHINE

Q.1. Why are the armatures of all the rotating electric machines laminated ?

Ans. The armature winding of both the D.C. and A.C. machines always have to deal with alternating current only. Therefore to reduce the eddy current losses, armature of all rotating electric machines are laminated while current in the field winding is always D.C.

Q.2. What are the different types of rotating electric machine ?

Ans. The most commonly rotating electric machines are as follows –

(i) D.C. machines which comprises generator and motor

(ii) Induction motor

(iii) Synchronous machines or A.C. machines which contains alternator and synchronous motor.

Q.3. Classify the rotating electric machines with their applications.
(R.G.P.V., Dec. 2010)

Ans. Electrical machinery can be mainly classified as D.C. machines and A.C. machines.

(i) ***D.C. Machines*** – D.C. machines are of three types –

(a) D.C. Series Machine – D.C. series machine has field winding in series with armature circuit.

(b) D.C. Shunt Machine – D.C. shunt machine has field winding across the armature circuit.

(c) D.C. Compound Machine – It has two field windings, one field winding across the armature and second field winding in series with the armature circuit.

These machines are easily adaptable for speed control and electric braking.

(ii) ***A.C. Machines*** – These machines are classified as under –

(a) Transformers – It is a electromagnetic device, which transfers electric power from one circuit to another without any change of frequency. However it is also employed with unity turns ratio for isolation purpose.

(b) Synchronous Machines – In these machines, the field poles may be on the stator or rotor.

When the field winding on rotor, it is excited with D.C. whereas stator winding handles three phase A.C. power. Rotor runs at synchronous speed N_s. Frequency (f) of the e.m.f. generated in armature is given by

$$f = \frac{N_s P}{120} \text{ Hz}$$

where, P = Number of field poles.

A synchronous machines is a doubly excited machine. It is used as an alternator for the generation of three phase power at all the generating stations.

(c) Induction Machines – These are of two types i.e., three-phase induction machines and single-phase induction machines.

Three-phase induction machines are of two types viz., squirrel cage induction motor (SCIM), which is used where starting torque or speed is not needed and slip ring induction motor (SRIM), which is used where control of starting torque or speed is required.

Single-phase induction motors are used, where single-phase low voltage (230 V, 50 Hz supply) is available as in homes, offices, classrooms, shops etc.

(d) A.C. Commutator Machines – As the name suggests, these machines are fed from A.C. source and are fitted with commutators. For wide speed control, three-phase Schrage motor (A.C. commutator machine) is reliable and introduces no harmonics into the supply system.

Q.4. What is meant by D.C. machine ?

Ans. A D.C. machine is an electro-mechanical energy conversion device. It can convert D.C. electrical power (EI) into mechanical power (ωT) and is called a D.C. motor. While, when it converts mechanical power into D.C. electrical power it is called a D.C. generator. From construction point of view, there is no difference between D.C. generator and D.C. motor.

Q.5. Write the necessity and material used for the following in a D.C. machine –

(i) ***Commutator*** *(ii)* ***Brush.*** ***(R.G.P.V., Dec. 2014)***

Ans. *(i)* ***Commutator*** – It is of cylindrical structure. It is built up of wedge-shaped segment of high conductivity hard-drawn copper to reduce its wear and tear-segments are insulated from each other by 0.8 mm thick mica.

The function of commutator is to convert an A.C. wave in the armature winding into D.C. wave at the output terminals in case of a D.C. generator. Whereas in case of D.C. motor it inverts the D.C. input wave into an A.C. wave in the armature winding i.e., rectifies the alternating e.m.f. induced in the armature coils and helps in the collection of current.

(ii) Brush – Brushes are housed in box-type brush holder attached to the stator end cover, or the stator yoke, brushes are made of carbon for small D.C. machines and electrographite for all D.C. machines. The function of brushes is to collect the current from the rotating commutator or to lead the current to it.

Q.6. Describe the constructional details of D.C. machine giving suitable diagram. ***(R.G.P.V., Dec. 2013)***

Or

Write down the constructional features of a D.C. machine with neat and suitable diagrams. ***(R.G.P.V., June 2016)***

Or

Describe D.C. machine with neat sketches in viewing of main parts and constructional details. ***(R.G.P.V., Dec. 2016, 2017)***

Ans. We know that every rotating electrical machine must posses (i) stator (or stationary member), and (ii) rotor (or rotating member). In a D.C. machine, the field winding is on the stator and the armature winding is on the rotor. The constructional details of a 2-pole D.C. machine is diagrametically shown in fig. 4.1.

Stator of a D.C. machine consists of yoke, (or frame), field winding, interpoles, compensating winding, brushes and endcovers.

Rotor consists of armature core, armature winding, commutator and shaft.

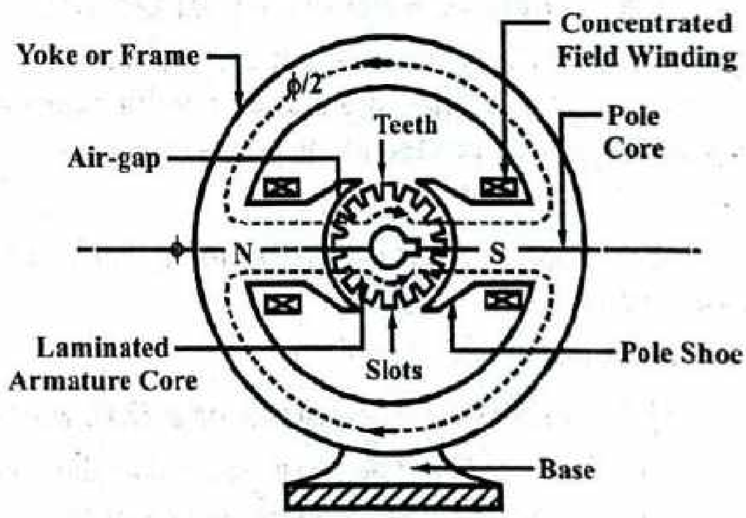


Fig. 4.1 The Constructional Detail of a 2-pole D.C. Machine

Yoke – It has mainly two functions –

(i) It provides path for magnetic flux ϕ and carries half of it.

(ii) It provides the mechanical support to the whole machine.

Yoke is made of unlaminated ferromagnetic material.

Field Poles – Field poles consists of pole core and pole shoe. The pole core is made from cast steel but the pole shoes is laminated and fixed to the pole core properly. The laminated pole is welded or bolted to the yoke.

Field (or Exciting) Winding – The pole is excited by a winding, wound around the pole core. This winding, called field or exciting winding, which is made from copper, the number of turns and cross-section of field winding depend upon the type of D.C. machine.

Interpoles or Commutating Poles – These are fixed to the yoke in between the main poles of a D.C. machine to ensure sparkless operation of the brushes at the commutator under the loaded condition of the machine.

Compensating Winding – These windings are placed in the slots cut in the pole faces of a D.C. machine. Compensating winding is also connected in series with the armature circuit.

Brushes – Refer the ans. of Q.5 (ii).

Armature Core – It is made from 0.35 to 0.50 mm thick laminations of silicon steel to keep down the iron losses. It serves for (i) Housing the armature coils in the slots and (ii) Providing the low-reluctance path to the magnetic flux $\phi/2$.

Armature Winding – These are made from copper. It consists of large number of insulated coils, each coil having one or more turns. The coils are usually former wound. These are placed in slots and properly connected in series and parallel depending upon the type of winding required. There are generally two types of winding viz., (i) Lap winding and (ii) Wave winding.

Commutator – Refer the ans. of Q.5 (i).

Shaft – On armature shaft are mounted (i) Hub H of commutator, (ii) Spider in big machines or armature core in small machines and (iii) Bearings. endcovers are connected to the yoke on one side and to the bearings and shaft on the other hand.

Q.7. Name the main parts of a D.C. machine and indicate their functions. ***(R.G.P.V., Dec. 2015)***

Ans. Refer the ans. of Q.6.

Q.8. Define speed regulation of a D.C. motor.

Ans. The speed regulation is defined as the change in speed from full load to no-load and is defined as a percentage of the full load speed.

$$\% \text{ speed regulation} = \frac{\text{N.L. speed} - \text{F.L. speed}}{\text{F.L. speed}} \times 100 = \frac{N_0 - N}{N} \times 100$$

Q.9. Write short note on classification of D.C. motor.

Ans. Similar to D.C. generators, according to their field excitation, D.C. motors can be classified as –

(i) Separately Excited D.C. Motors – The conventional diagram of a separately excited D.C. motor is shown in fig. 4.2 (a). Its voltage equation is

$$E_b = V - I_a R_a - 2v_b$$

(ii) Self Excited D.C. Motors – These motor can be further classified as follows –

(a) Shunt Motor – Its conventional diagram is shown in fig. 4.2 (b). Then,

$$I_{sh} = \frac{V}{R_{sh}},\ I_a = I_L - I_{sh}$$

$$E_b = V - I_aR_a - 2v_b$$

(b) Series Motor – Its conventional diagram is shown in fig. 4.2 (c). Then,

$$I_L = I_a = I_{se}$$

$$E_b = V - I_a(R_a + R_{se}) - 2v_b$$

(iii) Compound Motor – Its conventional diagram is shown in fig. 4.2 (d). Then,

$$I_{sh} = \frac{V}{R_{sh}},\ I_a = I_L - I_{sh},\ I_{se} = I_a$$

$$E_b = V - I_a(R_a + R_{se}) - 2v_b$$

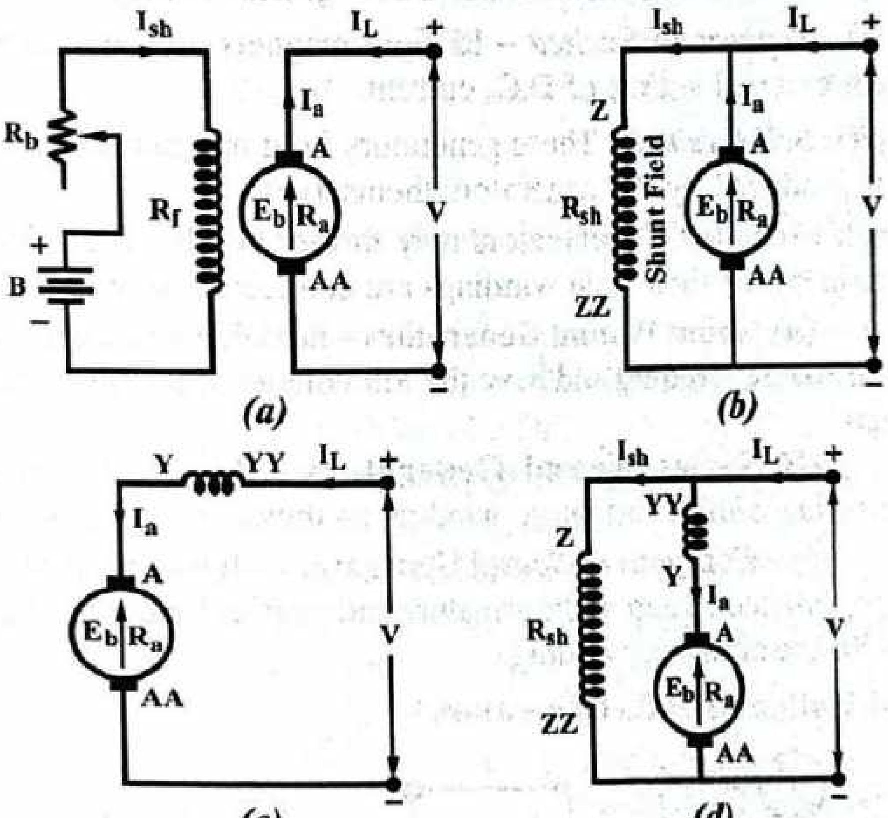


Fig. 4.2

In all the above voltage equations, the brush voltage drop v_b is some times neglected since its value is very small.

The compound motor can be further subdivided as –

(i) Cumulative Compound Motor – In these motors, the flux generated by both the windings is in the same direction, i.e.,

$$\phi_r = \phi_{sh} + \phi_{se}$$

(ii) Differential Compound Motors – In these motors, the flux generated by the series field winding is opposite to the flux generated by the shunt field winding, i.e.,

$$\phi_r = \phi_{sh} - \phi_{se}$$

Q.10. Classify self excited D.C. motor. ***(R.G.P.V., Dec. 2014)***

Ans. Refer the ans. of Q.9 (ii).

Q.11. State the types of D.C. motors. Discuss constructional details of any type of D.C. motor. ***(R.G.P.V., June 2013)***

Ans. Refer the ans. of Q.9 and Q.6.

Q.12. What do you mean by separately excited and self excited D.C. generator sketch following type of D.C. generator –

(i) Shunt wound (ii) Series wound (iii) Compound generator.
(R.G.P.V., Dec. 2013)

Or

Classify D.C. machines and explain them briefly. ***(R.G.P.V., June 2014)***

Ans. According to their field excitation, D.C. generators may be of two types –

(i) Separately Excited – Its field magnets are energised from an independent external source of D.C. current.

(ii) Self Excited – These generators field magnets are energised by the current produced by the generators themselves.

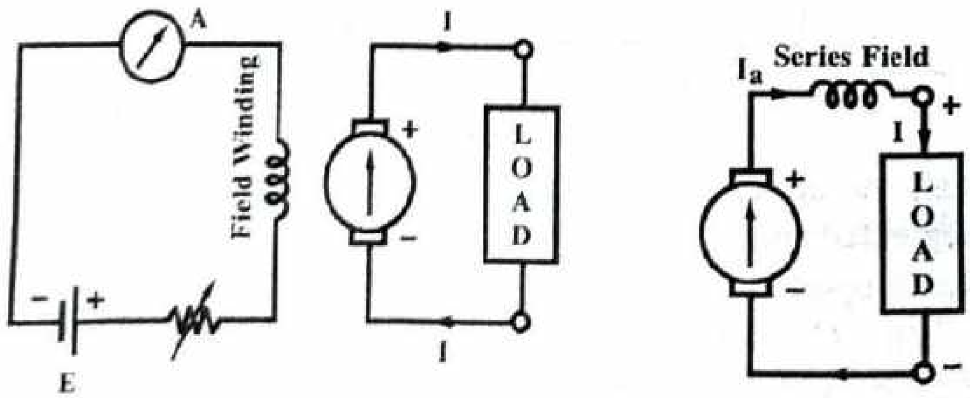
The self excited D.C. generators may further be classified according to the manner in which their field windings are connected to the armature.

(a) Shunt Wound Generators – Its field winding are connected across the armature winding and have the full voltage of the generator applied across them.

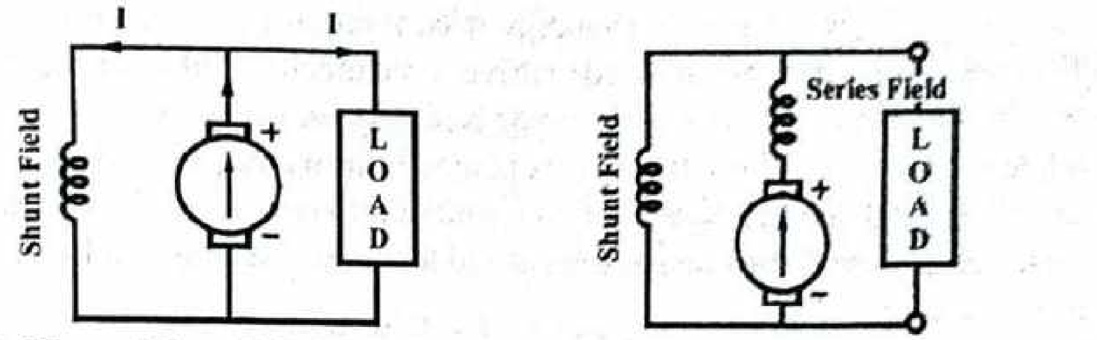
(b) Series Wound Generators – Its field windings are connected series with the armature winding as they carry full load current.

(c) Compound Wound Generators – It is consisting of a shunt field winding connected across the armature and a series field winding included in series with the armature winding.

Classification of D.C. Generators –



(a) Separately Excited *(b) Self Excited (Series-wound)*



(c) Shunt Wound Self Excited *(d) Compound Wound Self Excited*

Fig. 4.3

In the compound wound D.C. generators, the shunt field is generally stronger than the series field. When the series field assist the shunt field, the generator is known as cumulatively compound wound generator. Although, when the series field opposes the shunt field, the generator is called differentially compound wound generator.

Q.13. Write basic principle of operation and working of D.C. motor.
(R.G.P.V., June 2007, 2008, July 2008)

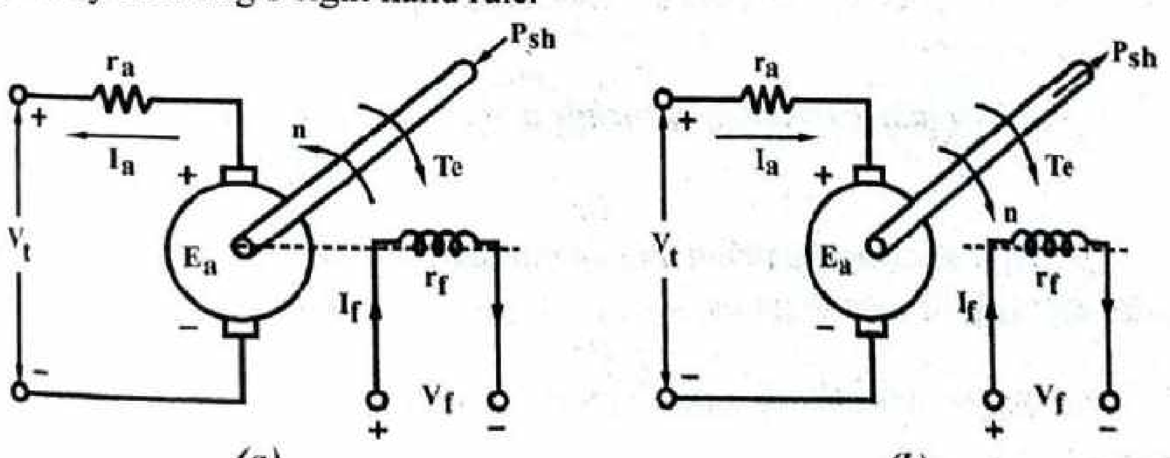
Or

Explain working principle of D.C. motor with necessary diagram.
(R.G.P.V., June 2017)

Or

With a neat diagram explain the working and principle of D.C. motor.
(R.G.P.V., May 2019)

Ans. In a D.C. generator, mechanical energy is converted into electrical energy. The electrical energy thus made available is supplied to the electrical load. The basic principle of working of a D.C. generator is Faraday's law of electromagnetic induction, which states that if there is a relative motion between a conductor placed in a magnetic field and in the field, a dynamically induced e.m.f. is produced in the conductor. The direction of the induced e.m.f. depends upon the direction of the magnetic field and the direction of motion and is given by Fleming's right hand rule.



(a) *(b)*

Fig. 4.4

In a D.C. motor, electrical energy is converted into mechanical energy. This mechanical energy is utilized to drive some mechanical load connected to the shaft of the motor. The D.C. motor basically works on the principle that when a current carrying conductor is placed in a magnetic field, mechanical force acts on it and as a result of it, the conductor starts rotating in a direction depending upon the direction of current and the field, and is given by Fleming's left hand rule.

The direction of current and torque are opposite in these two cases of generating and motoring action. Fig. 4.4 shows the principle of operation of both motor and generator.

Consider fig. 4.4 (b), for the generating action, the equation of the induced e.m.f. in terms of terminal voltage and armature resistance drop can be written as –

$$E - I_a R_a = V$$

or

$$E = V + I_a R_a$$

i.e., Induced e.m.f. in the armature = Terminal voltage available across the load + Armature resistance drop.

Similarly considering fig. 4.4 (a) for motoring action, the equation for the induced e.m.f., in terms of the terminal voltage and the armature resistance drop can be written as –

$$V - I_a R_a = E$$

or

$$E = V - I_a R_a$$

Hence, we can say that in a generator, mechanical power input = Electrical power developed + Electrical power lost in the armature circuit.

And for motor –

Electrical power input = Mechanical power developed + Loss in the armature circuit

or

Mechanical power developed = Mechanical power output at the shaft + Frictional losses.

Q.14. Explain the working principle and construction of D.C. machine. **(R.G.P.V., Dec. 2010)**

Or

Explain the constructional and operational feature of a D.C. machine with the help of neat diagram. **(R.G.P.V., Dec. 2012)**

Or

State basic principle of a D.C. motor. Draw diagram of a D.C. machine and name its parts. **(R.G.P.V., May 2018)**

Ans. Refer the ans. of Q.13 and Q.6.

Q.15. Explain construction, classification and working principle of D.C. machine. ***[R.G.P.V., Nov. 2018(O)]***

Ans. Refer the ans. of Q.6, Q.9 and Q.13.

Q.16. Derive the expression for generated voltage in D.C. machine. ***(R.G.P.V., Dec. 2006, 2007, 2011)***

Or

Derive e.m.f. equation of a D.C. motor/generator.

Or

Develop an e.m.f. equation for D.C. generator. (R.G.P.V., Dec. 2016, 2017)

Ans. When the armature in D.C. motor rotates, the conductor cuts the flux. According to law of electromagnetic induction, e.m.f. is induced in them whose direction is in opposite to the applied voltage. Because of the opposition direction, it is referred as *counter* or ***back e.m.f.***

The equivalent circuit of a motor shown in fig. 4.5. The rotating armature generating the back e.m.f. E_b as shown in fig. 4.5.

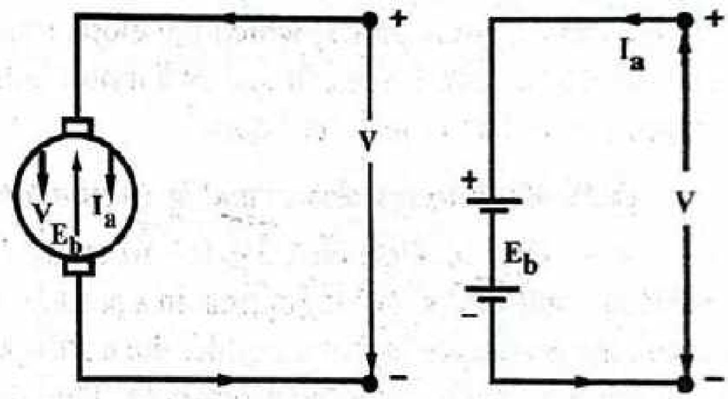


Fig. 4.5 Back e.m.f. in D.C. Machine

The average e.m.f. induced by the armature of a D.C. motor is equal to sum of the e.m.fs. of all the conductor connected in series on one parallel path.

Hence back e.m.f. is generated by one parallel path,

$$E_b = \frac{\text{Average e.m.f.}}{\text{Conductor}} \times \frac{Z}{A}$$

where, Z = Number of conductors, A = Parallel paths.

$$\therefore \qquad E_b = e_{av} \times \frac{Z}{A}$$

If ϕ is the air-gap flux per pole in webers and P the total number of poles in the machine then the total flux cut by one conductor in completing one revolution of armature = $P\phi$

Flux cut by one conductor per second = $P\phi \times \frac{N}{60}$

where, N is the speed of the machine in r.p.m.

Hence, back e.m.f. generated by one conductor of the armature

$$e_{av} = \frac{P\phi N}{60} \text{ volts}$$

Hence, total back e.m.f. generated by the armature of a D.C. machine is,

$$E_b = \frac{P\phi NZ}{60\,A} \text{ volts}$$

Q.17. Give reasons why starting current is high in D.C. motor ?
(R.G.P.V., June 2012)

Ans. A rotating D.C. motor generates a back e.m.f. which opposes the supply voltage and reduces the current drawn by the motor. When the motor is stationary, it cannot generate this back e.m.f. and so, the only opposition to current is the resistance of its windings which is relatively low. So, on startup, the current is large as the machine starts to run, the resulting back e.m.f., acts to reduce the current. Back e.m.f. depends on the armature speed. If speed is high, hence armature current I_a is small. If the speed is less, then E_b is less, hence more current flows, which develops motor torque. So we find that E_b acts like as a governer i.e., it makes a motor self regulating so that it draws as much current as is just necessary.

Q.18. What do you understand by commutation ? (R.G.P.V., Jan./Feb. 2007)

Ans. The e.m.f. generated in the armature conductor of the D.C. machine is alternating and as such the current in a particular conductor is in one direction, when the conductor is moving under the north-pole and in the reverse direction when it is moving under the south-pole. This reversal of current in a coil will take place when the two commutator segment to which the coil is connected are being short circuited by a brush. The process of reversal by a brush. The process of reversal of current in a coil is termed as ***commutation.*** With the help of commutation process, induced e.m.f. in the armature conductors of a D.C. generator can be made unidirectional.

Q.19. What is a function of back e.m.f. in a D.C. motor ?
(R.G.P.V., Jan./Feb. 2007)

Or

Give reason why induced e.m.f. in a D.C. motor is called back e.m.f. ?
(R.G.P.V., June 2012)

Ans. When motor armature rotates, the conductor also rotate and hence cut the flux. In accordance with the law of electromagnetic induction e.m.f. induced in them, whose direction, as found by Fleming's right hand rule, is in opposition to the applied voltage. Because of its opposing direction, it is referred to as counter e.m.f. or back e.m.f. E_b. The equivalent circuit of a motor is shown in fig. 4.5. The rotating armature generating the back e.m.f. E_b is like a battery of e.m.f. E_b put across a supply mains of V volts. Obviously, V has to drive I_a against the opposition of E_b. The power required to overcome this opposition is $E_b I_a$.

It will be seen that

$$I_a = \frac{\text{Net voltage}}{\text{Resistance}} = \frac{V - V_b}{R_a}$$

where R_a is the resistance of the armature circuit and $E_b = \phi ZN \times \left(\frac{P}{A}\right)$ volt.

Back e.m.f. depends on the armature speed. If speed is high, hence armature current I_a is small. If the speed is less, then E_b is less, hence more current flows, which developes motor torque. So we find that E_b acts like as a governer i.e., it makes a motor self-regulating so that it draws as much current as is just necessary.

Q.20. How a D.C. shunt generator work as a D.C. motor ? Explain.
(R.G.P.V., Jan./Feb. 2007)

Ans. A D.C. machine working as a generator must supply a power VI_L to the load circuit at a voltage V and current I_L. When a D.C. generator is loaded, its terminal voltage varies. The value of terminal voltage V and the load current I_L, when plotted gives a characteristic called the load characteristic or external characteristic.

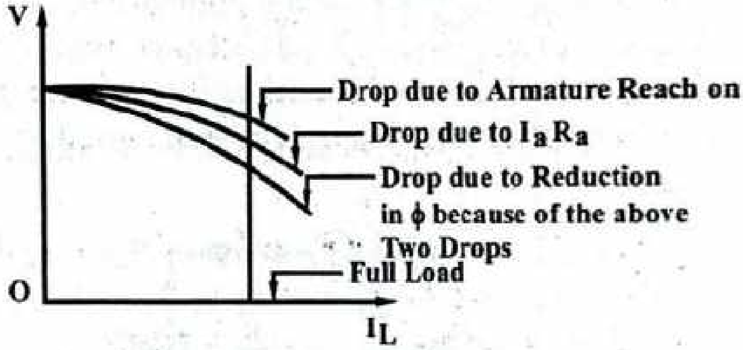


Fig. 4.6 Load Characteristic

When a separately excited generator is loaded by increasing I_L, a drop in terminal voltage occur. The drop in terminal voltage is due to two reasons, viz.

(i) I_aR_a drop in the armature circuit

(ii) Reduction in the air-gap flux due to the effect of armature reaction (armature reaction is the effect of flux produced by current flowing through the armature conductors on the flux created by the field winding current) and hence reduction in the no-load terminal voltage.

The load characteristic of a shunt generator will have a relatively more drooping characteristic as compared to a separately excited one. This is because in addition to the voltage drop due to I_aR_a and the reduction of air-gap flux due to the effect of the armature reaction there will be a voltage drop due to the reduction of current I_f. As $I_f = \frac{V}{R_f}$; if V is reduced, I_f will be reduced.

Q.21. Explain the different types of the characteristics of a D.C. machine as generator. Discuss the various characteristics among all types of D.C. generators with connection diagram.

Ans. The operating characteristics of D.C. generators give the relationship between the basic quantities, relevant to generator operation. These basic quantities are terminal voltage V_t, armature current I_a, field current I_f and speed N.

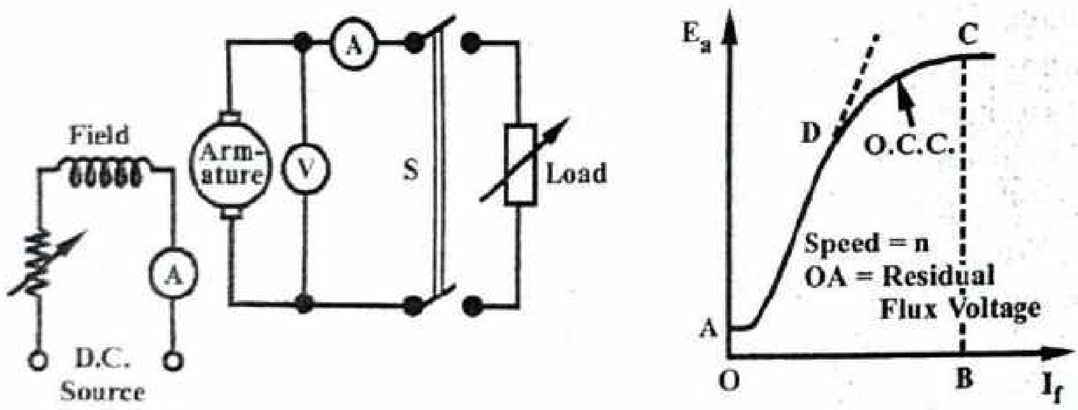
Following are the three most important characteristics or curves of a D.C. generator –

(i) No-load or magnetic or open-circuit characteristics (O.C.C.)
(ii) Internal or load characteristics
(iii) External or performance characteristics.

These are described underhere in all types of D.C. generators.

(i) Separately Excited Generators –

(a) No-load or Open-circuit Characteristics – This characteristic gives the variation of generated e.m.f. E_a with field current I_f, providing zero armature current and constant speed, as shown in fig. 4.7 (b). The connection diagram for getting no-load characteristics is shown in fig. 4.7 (a). In this case, field winding is not energised. Due to the presence of residual flux in the main poles, the residual flux voltage indicated by OA, as shown in fig. 4.7 (b). The field winding is now energised and the field current is increased in steps.

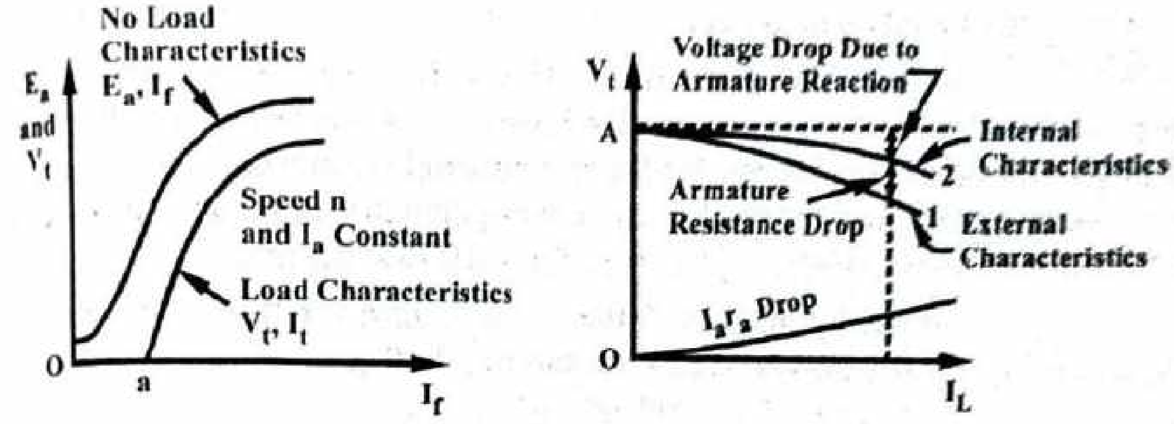


(a) Connection Diagram *(b) Its No-load Characteristic*

Fig. 4.7 Separately Excited Generator

(b) Load Characteristics – This characteristic gives the relationship between the terminal voltage V_t and field current I_f for constant armature current I_a and speed. In this case, vary the load and field currents, in such a manner that armature current I_a and speed remain constant, but V_t changes. By this characteristic, we can find the demagnetizing effect of armature reaction.

(c) External Characteristics – This characteristic gives the variation of armature terminal voltage V_t with load current I_L for constant speed and fixed field current, as shown in fig. 4.8 (b). The generator is run at rated speed and its field winding is excited to give rated terminal voltage at no-load. Now, close the switch S, and vary load resistances in steps for getting this curve.



(a) Load Characteristic

(b) External Characteristic of a Separately Excited Generator

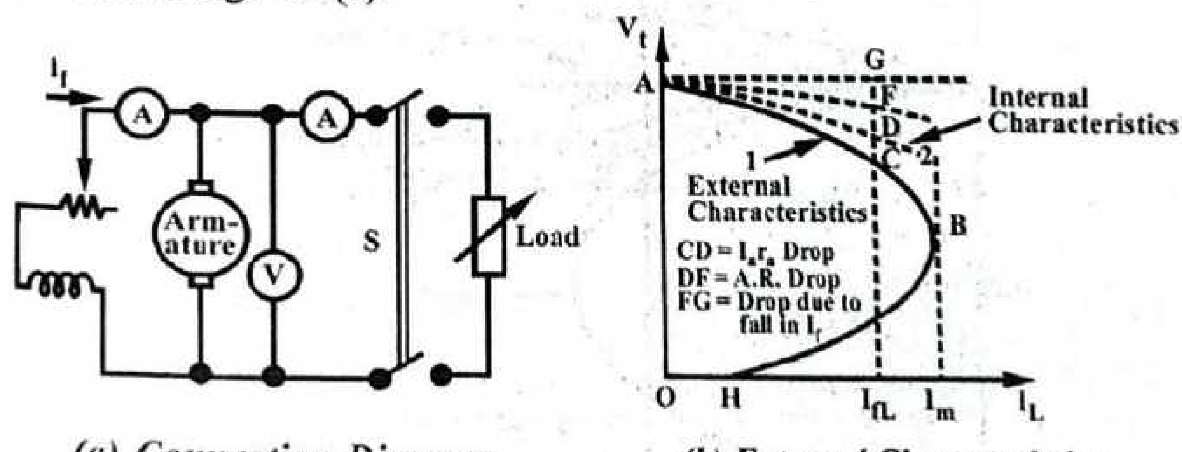
Fig. 4.8

(ii) Shunt Generators –

(a) No-load Characteristics – The characteristic of the self-excited shunt generator can be drawn with the help of connection diagram shown in fig. 4.9 (a). For obtaining the no-load characteristic curve, the field winding of the shunt generator is disconnected from the armature circuit and separately excited. The no-load characteristics will not differ from that obtained with the shunt excitation.

(b) Load Characteristics – The load characteristic can be plotted in the same manner as for the separately excited generator. There is a very small difference between two due to the different armature currents for shunt and separately excited generator. Fig. 4.9 (b) illustrates different characteristics or curves for the shunt generator.

(c) External Characteristics – For obtaining the external characteristics of a shunt generator, the generator is run at rated speed and field current is adjusted to give rated voltage at no-load, keeping the switch S closed, the load increases gradually in steps, thereby resulting the curve, which is shown in fig. 4.9 (b).



(a) Connection Diagram

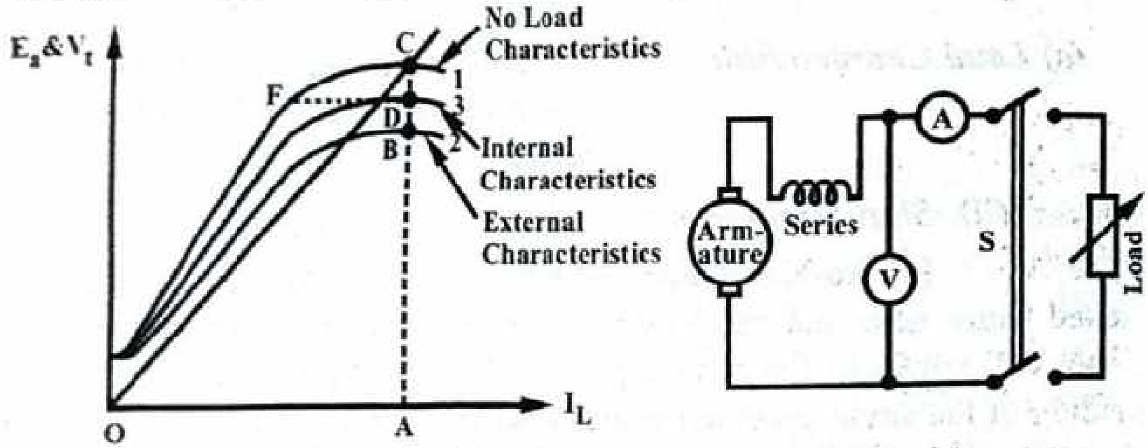
(b) External Characteristics

Fig. 4.9 Self Excited Shunt Generator

(iii) Series Generators –

(a) No-load Characteristics – In a series generator, the armature winding, field winding and load resistances are connected in series, therefore the field current is equal to the armature or load current. For obtaining no-load characteristics, the field of the series generator is separately excited from a low voltage source, as shown in fig. 4.10 (a) and (b).

(b) Load Characteristics – The curve for this characteristic of a series motor can also be seen from the fig. 4.10 (a).



(a) Series Generator Characteristics (b) Series Generator Connection Diagram

Fig. 4.10

(c) External Characteristics – For getting the external characteristics, connections of fig. 4.10 (b) are used. Curve 2 of fig. 4.10 (a) illustrates the external characteristics by varying the armature terminal voltage V_t so as to the load current is equal to the field current keeping the speed and the field current constant.

(iv) Compound Generators – These are more common generators, because these can furnish almost constant voltage from no-load to full-load. External characteristics of various types of D.C. compound generators are shown in fig. 4.11.

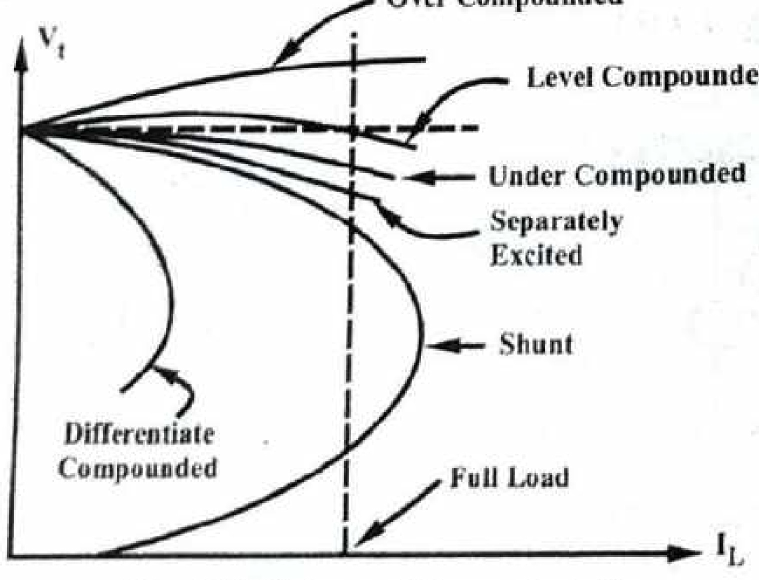


Fig. 4.11 External Characteristics

Q.22. What is torque ? What is the source of the torque in D.C. motor?
(R.G.P.V., Jan./Feb. 2007)

Ans. The term torque is meant the turning or twisting moment of a force about an axis. It is measured by the product of the force and the radius at which this force act.

Consider a pully of r metre acted upon by a circumferential force of F newton which casues it to rotate at N r.p.m., which is shown in fig. 4.12.

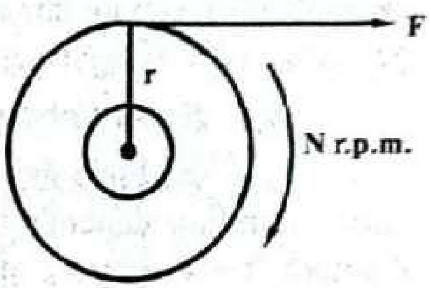


Fig. 4.12

Then torque, $T = F \times r$ N-m

Work done by this force in one revolution,

$= \text{Force} \times \text{Distance} = F \times 2\pi r$ joules

$\therefore$ Power developed,

$P = F \times 2\pi r.N$ watt $= F \times r.2\pi N$ watt

Since $2\pi N = \omega$ = Angular velocity in radian/ second and $F \times r = T$

Hence, power developed, $P = T \times \omega$ watt

If T_a be the torque developed by the armature of a motor running at ω radians per second,

Then power developed,

$$P = T_a \times \omega \text{ watt} = T_a \times 2\pi N \qquad ...(i)$$

Since we know that, electrical power converted into mechanical power in armature is $= E_b I_a$ watt ...(ii)

where, E_b = Back e.m.f., I_a = Armature current.

Equating the equations (i) and (ii), we get

$$T_a \times 2\pi N = E_b I_a \qquad ...(iii)$$

But, we know that, $E_b = \phi ZN \times \frac{P}{A}$ watt ...(iv)

Putting the value of E_b in equation (iii), we have

$$T_a \times 2\pi N = \phi ZN \times \frac{P}{A} \times I_a$$

Hence, $$T_a = \frac{1}{2\pi} \phi Z I_a . \left(\frac{P}{A}\right) \text{ N-m}$$

It is the required torque developed by a D.C. motor.

Source of the Torque – The source of a torque in a D.C. motor is conductor current (I_c).

Q.23. What are the different methods of speed control in D.C. motor ? Discuss in details. ***(R.G.P.V., Dec. 2011)***

Ans. The speed of a D.C. motor is given by the relation,

$$N = \frac{V - I_a R_a}{Z\phi}\left(\frac{A}{P}\right) = K.\frac{V - I_a R_a}{\phi} \text{ r.p.s.} \qquad ...(i)$$

where, V = Applied voltage
ϕ = Flux per pole
I_a = Armature current
R_a = Armature resistance

and $\frac{PZ}{A}$ = Constant = K

It may be seen from the above that the speed of D.C. motor can be controlled by varying the resistance in the armature circuit, varying the flux per pole and varying the applied voltage to the motor.

(i) Speed Control of Shunt Motors –

(a) Field or Flux Control Method – The flux generated by the shunt winding depends upon the current flowing through it (i.e. $\phi \propto I_{sh}$ and $I_{sh} = V/R_{sh}$). When a variable resistance R is connected in series with the shunt field winding as shown in fig. 4.13, the shunt field current ($I_{sh} = V/(R_{sh} + R)$ is decreased and hence the flux ϕ. Therefore, the shunt motor runs at a speed higher than the normal speed (since $N \propto 1/\phi$). The amount of increase in speed depends upon the value of variable resistance R.

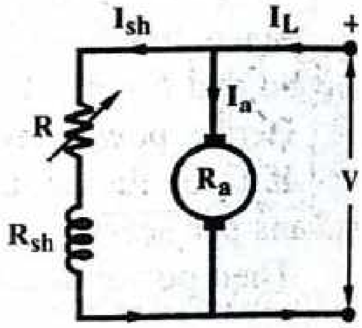


Fig. 4.13

This method is most commercial as very small power ($I_{sh}^2 R$) is wasted in the shunt field variable resistance due to relatively small I_{sh}. But the main demerit is that the speeds above normal only can be obtained.

(b) Armature Control Method – In a shunt motor, flux is constant when applied terminal voltage and shunt field resistance are constant. Consequently, shunt motor speed is directly proportional to induced e.m.f. (i.e., $N \propto E_b$ and $E_b = V - I_a R_a$). The value of E_b depends upon the drop in the armature circuit. When a variable resistance is connected in series with the armature as shown in fig. 4.14, the induced e.m.f. $[E_b = V - I_a(R_a + R)]$ is decreased and hence the speed. Therefore, the motor runs at a speed lesser than the normal speed.

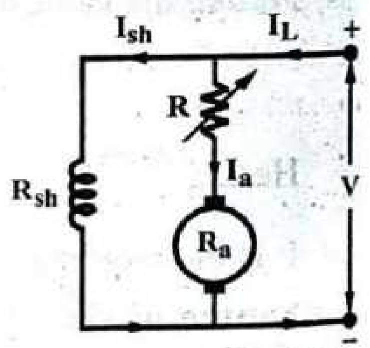


Fig. 4.14

This method is neither economical nor efficient as a large power ($I_a^2 R$) is wasted in control resistance R since it carries full armature current I_a.

(ii) Speed Control of Series Motors –

(a) Field Control Method – The speed of series motors can be controlled by varying the flux produced by the series field winding. The variation

of flux can be obtained as –

(1) Field Divertors – In field divertors method, a variable resistance R is connected in parallel with the series field winding as shown in fig. 4.15. Its effect is that it diverts the path of the current I_L drawn by the motor. Some of the current I_D flows through divertor and the current flowing through the series field winding is decreased which decreases the flux ϕ. Hence, the motor speed is increased ($N \propto 1/\phi$). Consequently by this method, only speeds above the normal speed can be obtained.

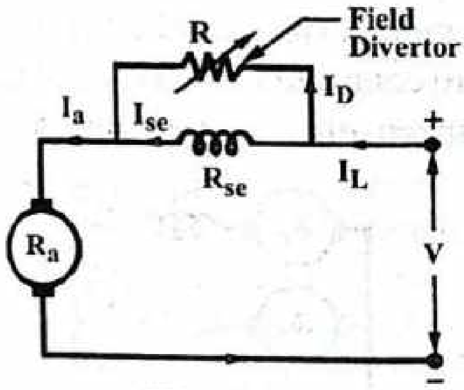


Fig. 4.15

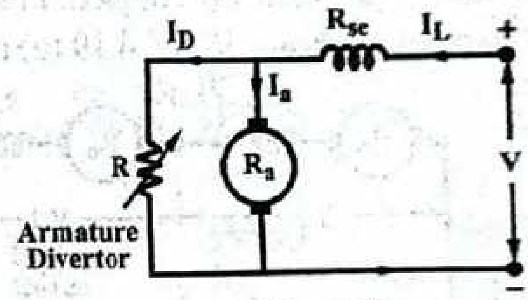


Fig. 4.16

(2) Armature Divertor – In this method, a variable resistance R is connected in parallel with the armature as shown in fig. 4.16. It diverts the path of the line current I_L. A part of the current I_D flows through the divertor and decreases the armature current I_a. For a given constant load torque, if I_a is decreased then ϕ must increase ($\because T \propto \phi I_a$). This gives in increase in current drawn by the motor and a fall in speed ($\because N \propto 1/\phi$). By varying the divertor resistance, any speed below normal can be achived by this method.

(3) Tapped Field Control – In this method, the number of turns of the series field winding can be changed by short circuiting a part of it as shown in fig. 4.17. We know that flux produced by the winding depends upon the ampere turns (i.e., $\phi \propto I_{se} \times$ Number of turns). As the number of turns are decreased, the motor speed is increased ($N \propto 1/\phi$). Therefore, only speeds above the normal speed can be achieved by this method.

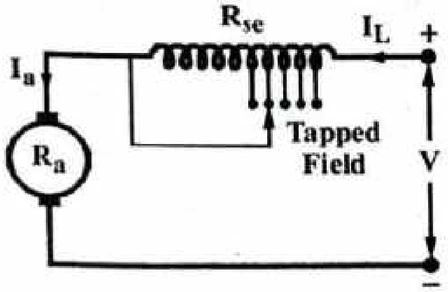


Fig. 4.17

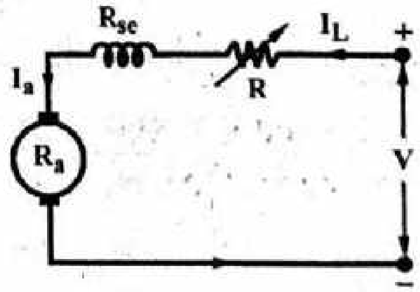


Fig. 4.18

(b) Armature Control Method – In this method, a variable resistance R is connected in series with the armature as shown in fig. 4.18. If

the current taken by the motor is constant, flux is constant, then speed depends upon the induced e.m.f. [i.e., $N \propto E_b$ where $E_b = V - I_a(R_a + R_{se})$]. With the addition of variable resistance, induced e.m.f. decreases [$E_b = V - I_a(R_a + R_{se} + R)$] and hence the speed. By changing the variable resistance, any speed below normal speed can be achieved.

(c) Voltage Control Method – In this method, the voltage across the series motors is changed by connecting them in series or in parallel or the combination of both.

Here, we consider only two similar series motors (for simplicity) whose shafts are mechanically coupled. Firstly they are connected in series and then in parallel as shown in fig. 4.19 (a) and (b) respectively.

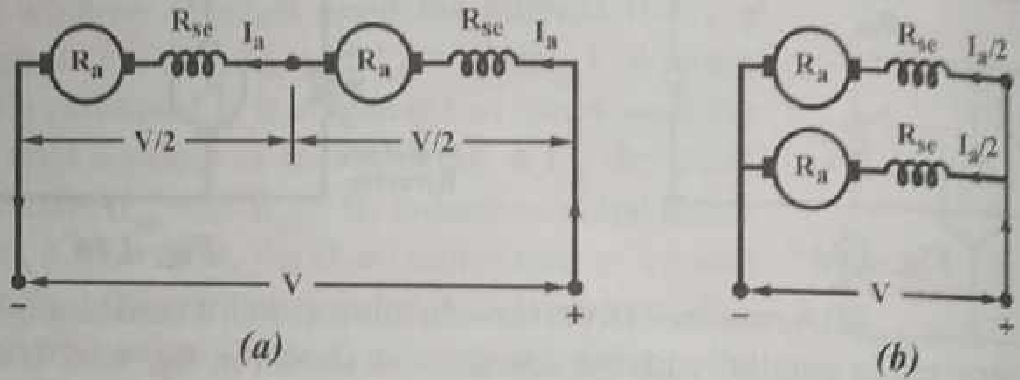


Fig. 4.19

When in series –

$$\text{Speed, } N_1 \propto \frac{E_{b1}}{\phi_1} \propto \frac{\frac{V}{2} - I_a(R_a + R_{se})}{I_a}$$

Neglecting drops,

$$N_1 \propto \frac{V/2}{I_a} \propto \frac{V}{2I_a} \quad \text{...(i)}$$

When in parallel –

$$\text{Speed, } N_2 \propto \frac{E_{b2}}{\phi_2} \propto \frac{V - \frac{I_a}{2}(R_a + R_{se})}{I_a/2} \propto \frac{2V}{I_a} \quad \text{...(ii)}$$

From equations (i) and (ii), yields

$$\frac{N_2}{N_1} = \frac{2V}{I_a} \times \frac{2I_a}{V} = 4$$

or

$$N_2 = 4N_1 \quad \text{...(iii)}$$

Hence, when the motors are connected in series, low speeds are achieved and when they are connected in parallel high speeds (nearly 4 times greater) are obtained.

(iii) Speed Control of Separately Excited Motors –

Ward-Leonard System – This system is employed to supply variable voltage to the motor. As shown in fig. 4.20, a D.C. generator G is mechanically coupled with a prime mover PM which rotates the generator at a constant speed. The field winding of the D.C. generator is connected to a constant voltage D.C. supply line through a field regulator and reversing switch. The D.C. motor M is fed from the generator G and its field winding is connected directly to a constant D.C. supply line.

The voltage of the generator fed to the motor, can be varied from zero to its maximum value by means of its field regulator. By reversing the direction of the field current by means of the reversing switch, the polarity of the generated voltage can be reversed and thus the direction of rotation of motor M. Thus, the speed and direction of rotation both can be controlled very accurately by this method.

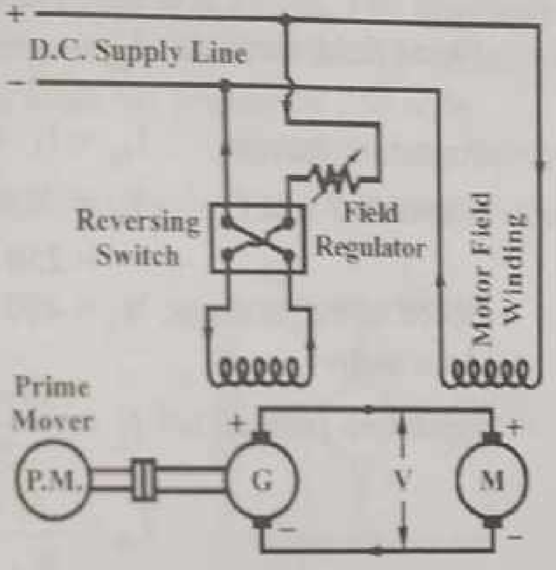


Fig. 4.20

NUMERICAL PROBLEMS

Prob.1. A six pole lap wound D.C. generator has 720 conductors, a flux of 40 mWb per pole is driven at 400 rpm. Find the generated e.m.f.

(R.G.P.V., June 2017)

Sol. Given, P = 6. For lap winding A = P, N = 400 r.p.m., ϕ = 40 mWb = 40×10^{-3} Wb, Z = 720.

Now, the generated e.m.f. can be determined as –

$$E = \frac{NP\phi Z}{60A} = \frac{400 \times 6 \times 40 \times 10^{-3} \times 720}{60 \times 6} = 192 \text{ V} \qquad \textbf{Ans.}$$

Prob.2. Calculate the generated e.m.f. of a 8-pole wave wound D.C. generator which is having 720 conductors, flux per pole is 40 mWb and is driven at 400 rpm. ***(R.G.P.V., May 2018)***

Sol. Given, N = 400, Z = 720, $\phi = 40 \times 10^{-3}$ Wb

P = 8, A = 2 (wave winding)

The generated e.m.f. can be obtained as

$$E = \frac{NP\phi Z}{60A} = \frac{400 \times 8 \times 40 \times 10^{-3} \times 720}{60 \times 2} = 768 \text{ V} \qquad \textbf{Ans.}$$

Prob.3. A shunt generator delivers 50 kW at 250 V and 400 r.p.m. The armature and field resistances are 0.02 Ω and 50 Ω respectively. Calculate the speed of the machine running as shunt motor and taking 50 kW input at 250 V.

(R.G.P.V., June 2013)

Sol. As a generator

Load current, $I_L = \frac{50 \times 10^3}{250} = 200 \text{ A}$

Shunt field current, $I_{sh} = \frac{V}{R_{sh}} = \frac{250}{50} = 5 \text{ A}$

Armature current, $I_{a_1} = I_L + I_{sh} = 200 + 5 = 205 \text{ A}$

Generated e.m.f., $E_1 = V + I_{a_1} R_a + \text{Brush drop}$

$$= 250 + (205 \times 0.02 + 0) = 254.1 \text{ V}$$

Speed of the generator, $N_1 = 400$ r.p.m.

As a motor

Input line current, $I_L = \frac{50 \times 10^3}{250} = 200 \text{ A}$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{50} = 5 \text{ A}$$

Armature current, $I_{a_2} = I_L - I_{sh} = 200 - 5 = 195 \text{ A}$

Generated e.m.f., $E_2 = V - I_{a2} R_a - \text{Brush drop}$

$$= 250 - (195 \times 0.02) - 0 = 246.1 \text{ V}$$

$$\frac{N_2}{N_1} = \frac{E_2}{E_1} \times \frac{\phi_1}{\phi_2}$$

Since the field current is constant, $\phi_2 = \phi_1$

$$\therefore \quad N_2 = \frac{E_2}{E_1} N_1 = \frac{246.1}{254.1} \times 400 = \mathbf{387.41\ r.p.m.}\ \text{Ans.}$$

Prob.4. A 30 kW, 33 V D.C. shunt generator has armature and field resistance of 0.05 ohm and 100 ohm respectively. Calculate the total power developed by the armature when it delivers full output power.

(R.G.P.V., May 2019)

Sol. Load current, $I_L = \frac{30 \times 1000}{33} = 909.09 \text{ A}$

Shunt field current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{33}{100} = 0.33 \text{ A}$$

We know that, armature current, I_a can be calculated as,

$$I_a = I_L + I_{sh}$$

$$I_a = 909.09 + 0.33 = 909.42 \text{ A}$$

Generated e.m.f. $(E_g) = V + I_a R_a$

$$= 33 + 909.42 \times 0.05 = 78.47 \text{ V}$$

$\therefore$ Total power developed,

$$P = E_g . I_a$$

$$= 78.47 \times 909.42 = 71362.18 = \mathbf{71.36 \text{ kW}} \quad \textbf{Ans.}$$

Prob.5. The armature of a 4-pole, lap wound shunt generator has 120 slots with 4 conductor per slot. The flux per pole is 0.05 Wb. The armature resistance is 0.05 Ω and shunt field resistance is 50 Ω. Find the speed of the machine when supplying 450 A at a terminal voltage of 250 volts.

(R.G.P.V., June 2009)

Sol. Fig. 4.21 shows the schematic diagram of a shunt generator, supplying a load of resistance R_L.

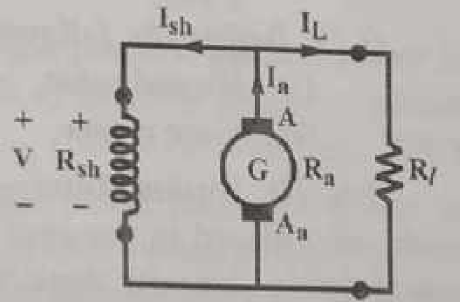


Fig. 4.21 Schematic Diagram of Shunt Generator

Here given,

Terminal voltage, V = 250 volt

Load current, $I_L = 450$ A

Shunt field resistance, $R_{sh} = 50\ \Omega$

Armature resistance, $R_a = 0.05\ \Omega$

Shunt field current,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{50} = 5 \text{ A}$$

Armature current,

$$I_a = I_L + I_{sh} = 450 + 5 = 455 \text{ A}$$

Generated e.m.f.,

$$E_g = V + I_a R_a = 250 + 455 \times 0.05 = 272.75 \text{ V}$$

Also generated e.m.f., $E_g = \dfrac{P\phi NZ}{60\ A}$ volt ...(i)

Here number of poles, P = 4

Flux per pole, $\phi = 0.05$ Wb

Number of slots on armature = 120

Conductors per slot = 4

Thus total number of conductors on armature Z = 120 × 4 = 480

Since the armature is lap wound, therefore the number of parallel paths, A = P = 4

Substituting these values in the equation (i), we have

$$272.75 = \frac{4 \times 0.05 \times N \times 480}{60 \times 4}$$

Speed of rotation, $N = \dfrac{272.75 \times 60 \times 4}{4 \times 0.05 \times 480} = \mathbf{682 \text{ r.p.m.}}$ **Ans.**

CONSTRUCTION, CLASSIFICATION & WORKING PRINCIPLE OF INDUCTION MACHINE

Q.24. What do you mean by induction machine ?

Ans. Induction machines are also known as asynchronous machines i.e. the machines which never run at a synchronous speed. Induction motors may be single phase or three-phase. The single-phase induction motors are usually built in small size (upto 3 H.P). The three-phase induction motors are the most commonly used A.C. motors in the industry because they have simple and rugged construction, low cost, high efficiency, reasonably good power factor, self starting torque and low maintenance.

Q.25. Define the following –
(i) Wound rotor
(ii) Cage rotor.

Ans. ***(i) Wound Rotor*** – The winding of a wound rotor is polyphase with coils placed in the slots of the rotor core. The rotor is wound and is connected in star with three loads brought out of the machine via slip rings placed on the shaft. The slip rings are tapped by means of copper carbon brushes. This construction is generally employed for large size machines to be used where the starting torque requirements are stringent. External resistance can be inserted in the rotor circuit through slip rings for reducing the starting current and simultaneously improving the starting torque.

(ii) Cage Rotor – It has solid bars of conducting material placed in rotor slots and shorted through end rings on each side. The rotor circuit of this machine cannot be tapped and the machine has a low starting torque, while it has excellent running performance. Therefore, it cannot be used, where a high starting torque is required.

Q.26. Draw and explain the construction of a single-phase induction motor with neat sketches. ***(R.G.P.V., Dec. 2011)***

Ans. Induction machines are also known as asynchronous machines i.e., the machines which never run at a synchronous speed.

Construction and Working of Single-phase Induction Motor– Constructionally, a single phase induction motor is more or less similar to a polyphase induction motor, except that, (i) its stator is provided with a single phase winding and (ii) a centrifugal switch is used in some types of motors, in order to cut out a winding, used only for starting purpose. A single phase induction motor comprises a single phase distributed winding on the stator and normal squirrel cage rotor. When fed from a single phase supply its stator winding produces a flux which is only alternating i.e., one which alternates

along one space axis only. Now, an alternating flux acting on a stationary squirrel cage rotor can not produce rotation. However, if the rotor of such a machine is given an initial start by hand (or small rotor) or otherwise, in either direction, then immediately a torque arise and the motor accelerates to its final speed. Fig. 4.22 shows construction of 1-ϕ I.M. There are two important methods of analysis this motor, viz (i) double field theory and (ii) cross-field theory.

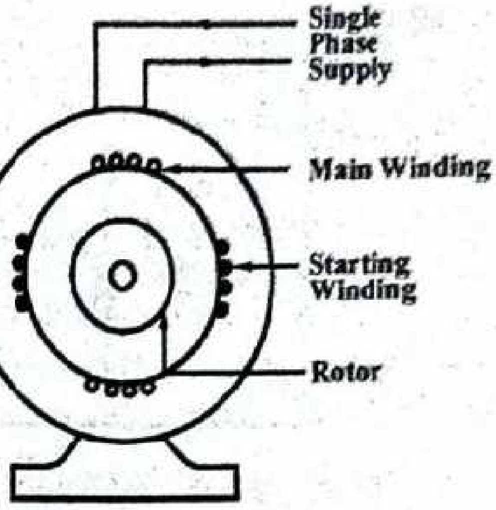


Fig. 4.22 Single Phase Induction Motor

Q.27. Why in its elementary form, the single phase induction motor is not self starting ? Describe various methods of starting of single phase induction motors. ***(R.G.P.V., Jan./Feb. 2007)***

Ans. When the stator winding of a single phase induction motor is connected to a single phase alternating current, an alternating phase magnetic field is produced. This magnetic field acting on the stationary squirrel cage rotor, which cannot produce the starting torque needed for the motor. Hence single phase induction motors are not self starting.

An alternating flux acting on a stationary squirrel cage rotor cannot produce rotation. If the rotor of a single phase motor is given an initial start by hand or by means in either direction, then immediately a torque developed in the motor and motor accelerates to its final speed as it is not loaded heavily.

The selection of a suitable induction motor and choice of its starting method, depend upon the following –

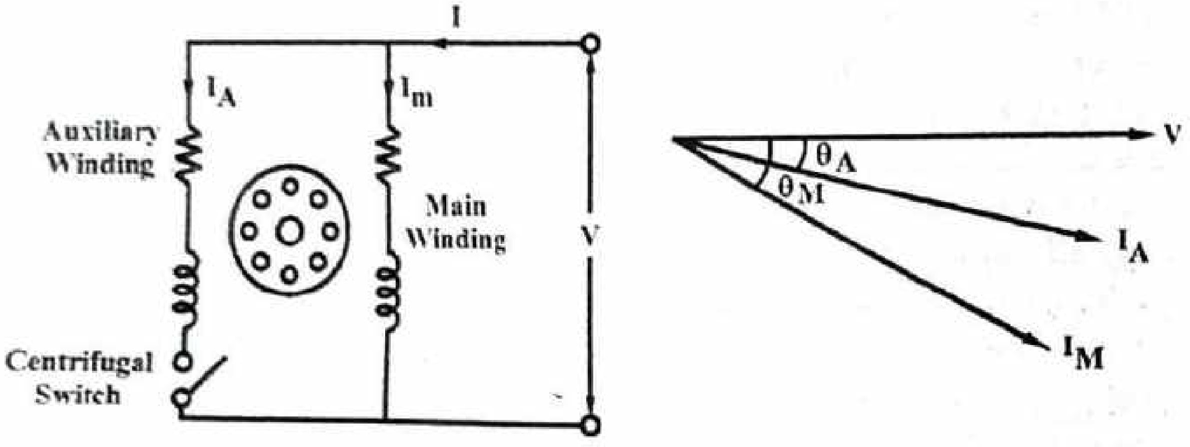
(i) Torque-speed characteristic of load from stand still to the normal operating speed.

(ii) The duty cycles, and

(iii) The starting and running line-current limitations as imposed by the supply authority.

Hence, several method which have been developed for the starting of single-phase induction motors, may be described as follows –

(i) Split-phase Induction Motors – In this, the stator has two windings i.e., main and auxiliary. The auxiliary winding is displaced in magnetic position from the main winding and is connected in parallel with it, as shown in fig. 4.23 (a). The main winding has a relatively high reactance and low resistance, whereas its vice-versa in auxiliary winding, generally these two windings are displaced in space by 90° electrical degrees. The main winding is usually of heavier wire section and is distributed in more slots.



(a) Split-phase Induction Motor *(b) Phasor Diagram*

Fig. 4.23

Split-phase motors are usually built for a phase splitting of about 30 degree as shown in the phasor diagram of fig. 4.23 (b). Phasors I_A and I_M represents the stator winding currents,which are displaced in space and time so yield a motor torque. Split phase motors do not have high locked rotor torque because the phase displacement between the two currents is less.

The split phase motor will draw excessive amount of power from the line if the auxiliary winding continues to be in the circuit. This may result in rapid overheating, and inefficient and noisy performance. Hence a starting switch is normally provided on the rotor, which automatically disconnects the starting winding at a speed approximately 75% of the synchronous speed. These starting switches may be centrifugally operated or magnetically operated.

These motors have moderate starting torque and low starting current. Typical ratings are 1/20 to 0.5 hp and are cheapest in this range. These motors find applications in washing machine, oil burners, fans and blowers, grinders, refrigerators, centrifugal pumps etc.

(ii) Capacitor Start Induction Motors – It has two capacitors in the auxiliary winding. Both C_1 and C_2 are in the circuit during starting. After the motor has made-up speed, centrifugal switch opens and disconnects the capacitor C_2, at a speed approximately 70% of the rated speed. The auxiliary winding and capacitor C_1 remain in the circuit during running condition too. Thus the motor is actually, a two-phase motor. The use of capacitor C_1 during running

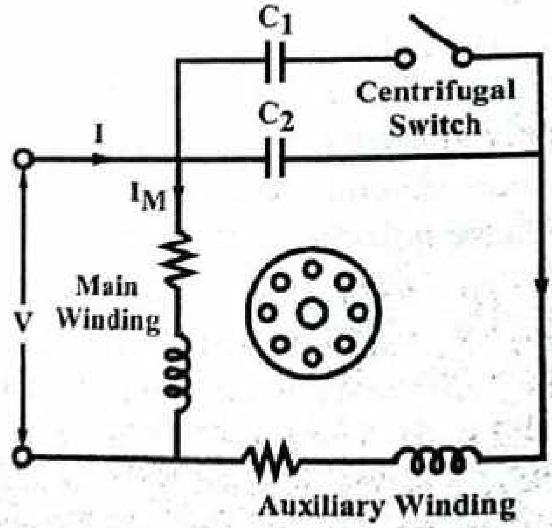


Fig. 4.24 Capacitor Start Induction Motor

condition improves the power factor, the two phase operation results in better efficiency. This type of motor is built in ratings from 1/8 to 1.0 hp, and are used in compressors, pumps, conveyors and other torque loads. Fig. 4.24 shows capacitor start induction motor.

(iii) Shaded-pole Induction Motors – A shaded-pole induction motor is a single phase induction motor that has an auxiliary winding short-circuited on itself and is also displaced in magnetic position from the main winding. This is built in ratings 1/20 hp or less. The shaded-pole induction motor is simplest in construction, low in cost, and extremely rugged and reliable. However, its efficiency is poor. Fig. 4.25 shows a schematic representation of a simple shaded-pole induction motor. Salient poles are provided on the stator which are excited by the concentrated winding. To start these motors, apart of these poles an auxiliary short-circuited winding is mounted, which is called ***shading coil,*** hence the name shaded pole induction motor.

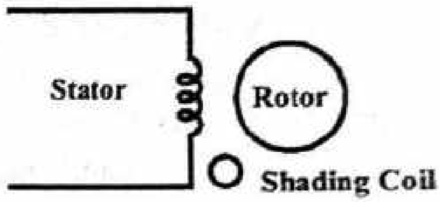


Fig. 4.25 Shaded-pole Induction Motor

Q.28. With the help of neat sketches explain the construction and working principle of split phase induction motor. ***(R.G.P.V., May 2019)***

Ans. Refer the ans. of Q.27 (i)

CONSTRUCTION, CLASSIFICATION & WORKING PRINCIPLE OF SYNCHRONOUS MACHINE

Q.29. What is meant by synchronous machine ?

Ans. A machine which converts mechanical power into A.C. electrical power is know as synchronous generator or alternator. A synchronous machine is an A.C. machine whose satisfactory operation depends upon the maintenance of the following relationship –

$$N_S = \frac{120\,f}{P} \text{ or } f = \frac{PN_S}{120}$$

where N_S is the synchronous speed in r.p.m. and f is the supply frequency and P is the number of poles of the machine.

Q.30. Why synchronous machine is called as synchronous ? Define synchronous speed. ***(R.G.P.V., Dec. 2014)***

Ans. Basically, synchronous machine is a three phase A.C. machine in which the rotor and the magnetic field of the machine rotate in synchronism with each other i.e., they both rotate at the same speed. That is why it is called synchronous machine.

Synchronous Speed – Synchronous speed is the speed at which an alternator must run in order to generate an e.m.f., of the required frequency. It is denoted by N_s.

$$N_s = \frac{120\,f}{P}$$

Q.31. How synchronous motor is different than induction motor in its principle of working ? ***(R.G.P.V., March/April 2010)***

Ans. A synchronous motor is electrically identical with an alternator or A.C. generator. It runs either at synchronous speed or not at all i.e., while running it maintains a constant speed. The only way to change its speed is to vary the supply frequency (because $N_s = 120\ f/P$).

It is not inherently self starting. It has to be run upto synchronous (or near synchronous) speed by some means before it can be synchronized to the supply.

On the other hand, induction motor starts up from rest and needs no extra starting motor and has not to be synchronized. Its starting arrangement is simple especially for squirrel-cage type motor.

Q.32. Explain the constructional features of synchronous generators. What are two types of generator ? ***(R.G.P.V., June 2005)***

Ans. A synchronous machine is a ***doubly excited A.C. machine,*** because its field winding is energised from a D.C. source and its armature winding is connected to an A.C. source.

During its working as a generator, synchronous machine delivers A.C. power. However, the field winding of a synchronous machine always absorbs power from a D.C. source. Since a synchronous generator delivers A.C. output, it is also known as an ***alternator.***

Similar to other rotating electrical machine, a synchronous machine, consists of two basic element i.e., stator and rotor. The synchronous machines are of two types depending upon the geometrical structure of the rotor, viz salient pole type and smooth cylindrical type synchronous machines.

(i) Salient Pole Type – Salient pole alternators are slow speed machine. It has large number of projecting poles, which is built up of thin steel plates that are clamped by means of heavy end plates of cast iron, or steel of good magnetic quality, and secured by studs or rivets, such synchronous machines are characterised by their large diameters and short-axial length. Slots are cut in the pole shoe for accommodating the ***damper winding.*** Damper winding in synchronous machine serve the following functions –

(a) It is equivalent to the squirrel cage rotor of induction motor and hence, synchronous machine with damper winding can be started as an induction motor.

(b) The damper winding helps in reducing the over voltages under abnormal conditions.

(c) Rotor oscillations are damped out.

A four-pole salient pole synchronous machine is shown in fig. 4.26.

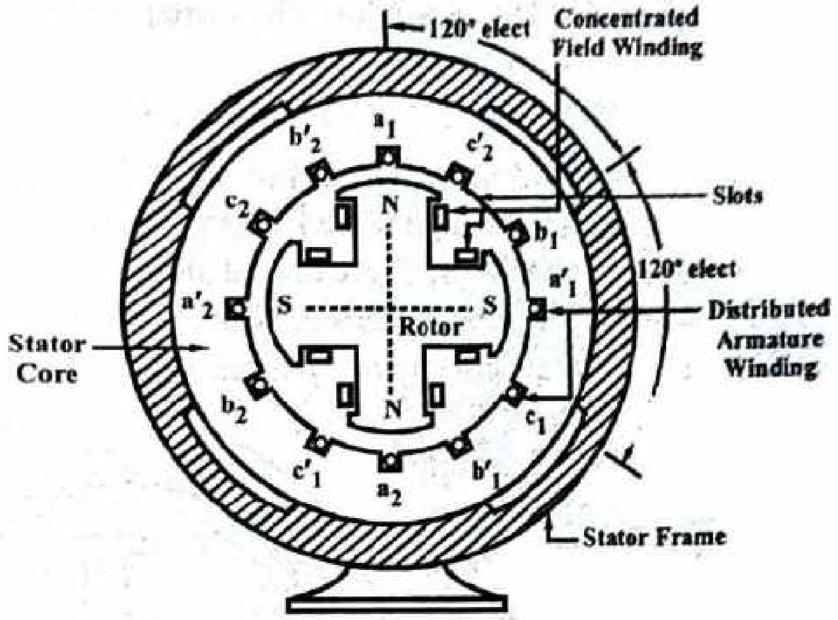


Fig. 4.26 4-Pole, 3-phase Salient Pole Construction

(ii) Smooth Cylindrical Pole Type – Cylindrical type rotor consists of a smooth forged steel cylinder, having a number of slots milled out at intervals along the outer periphery for accommodating field coils. The cylindrical rotor machine of two poles shown in fig. 4.27. The central polar areas are surrounded by the field windings placed in slots as shown in figure. The field coils are so arranged around these polar areas that flux density is maximum on the polar central line and gradually falls away on either side. Such rotors have small diameters and long axial length. It is used for steam turbine-driven alternators i.e., turbo alternators, which run at very high speeds and gives better balance and quieter operation with less windage losses.

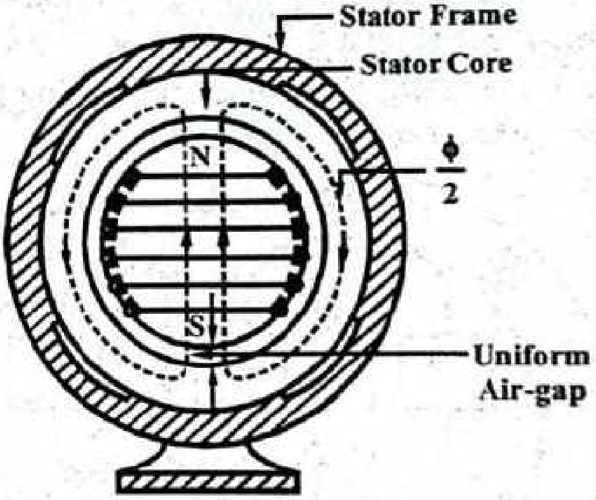


Fig. 4.27 2-Pole Cylindrical Rotor

(iii) Stator – The stator of both type of synchronous machines is nilar to the induction motor, stator.

The synchronous machine stator consists of a cast-iron frame, which ports the armature core having slots on its inner periphery for housing the ature conductors and polyphase distributed winding placed in the stator s, bearing, base etc., as shown in fig. 4.26.

Q.33. Give the constructional details of 3-ϕ stator winding synchronous hine with rotating field. ***(R.G.P.V., Dec. 2005)***

Ans. The stator winding or armature winding in 3-ϕ synchronous machines are different from those used in D.C. machine. The armature windings used in 3-ϕ synchronous machines are of two types –

(i) Single-layer winding (ii) Double-layer winding.

(i) Single-layer Winding – The fundamental principle of such winding is illustrated in fig. 4.28 which shows a single-layer, one turn, full pitch winding for a four-pole generator. There are 12 slots in all, giving 3 slots per pole or 1 slot/phase/pole. The pole pitches are obviously 3. It is seen in the fig. 4.28, that R phase starts at slot No. 1, passes through slots 4, 7 and finishes at 10. The Y-phase starts 120° afterwards, i.e., from slot No. 3 which is 2 slots away from the start of R-phase. It passes through slots 6, 9 and finished at 12. Similarly, B-phase starts from slot No. 5 i.e., two slots away from the start of Y-phase. It passes through slots 8, 11 and finishes at slot No. 2, the developed diagram is shown in fig. 4.29. The ends of the windings are joined to form a star point for a Y-connection. It is variously fig. 4.30 referred to as concentric or chain winding. Sometimes, it is of simple bar type or wave winding.

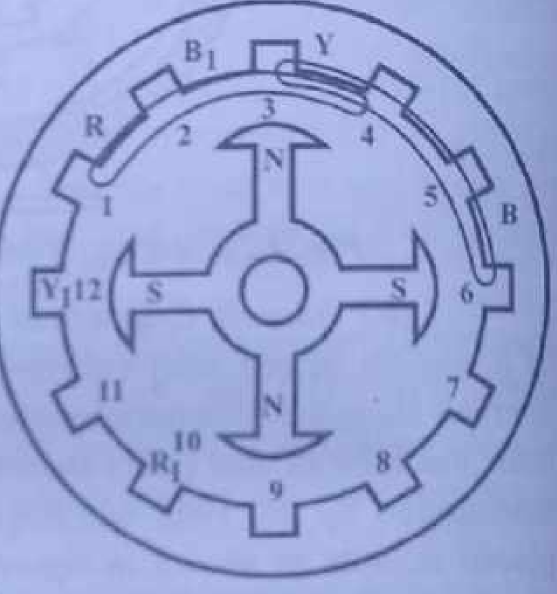


Fig. 4.28

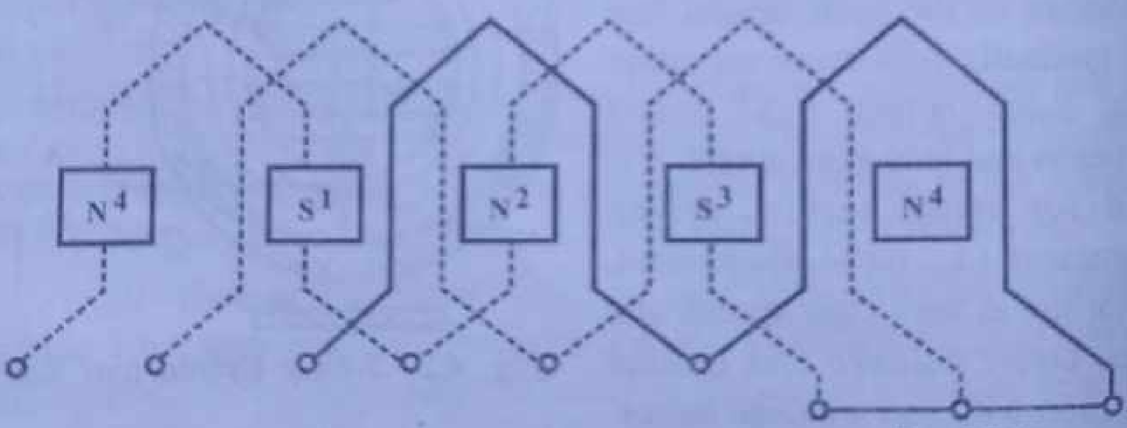


Fig. 4.29

(ii) Double-layer Winding – This winding is either of wave-wound type or lap-wound type. It is most commonly used in synchronous machine and induction motors.

Usually, the number of slots in stator (armature) is a multiple of the number of poles and the number of phases. Thus, the stator of a 4-pole, 3-phase synchronous machine may have 12, 24, 36, 48, etc., slots all of which are seen to be multiple of 12 (i.e., 4 × 3).

The number of stator slots is equal to the number of coils (which are all of the same shape). Hence, each slot contains to coil sides, one at the bottom of the slot and the other at the top. The coils overlap each other.

For the 4-pole, 24-slot stator machine shown in fig. 4.30. The pole pitch is 24/4 = 6. For maximum voltage, coil should be full pitched. It means that, if one side of coil is in slot No. 1, the other side should be in slot No. 7, the two slots 1 and 7 being one pole-pitch or 180° (electrical) apart. To make matters simple, coils have been labelled as 1, 2, 3 and 4 etc.

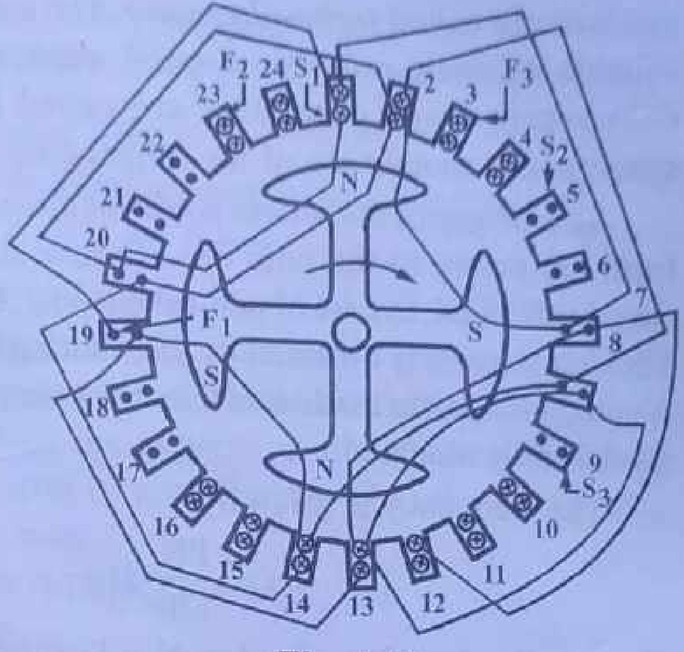


Fig. 4.30

Q.34. Write the principle of operation of synchronous motor.

(R.G.P.V., May 2018)

Or

What is the basic working principle of synchronous machine ?

(R.G.P.V., Dec. 2012)

Ans. Synchronous machine operates on the principle of electromagnetic induction. Basically it is very similar to the D.C. generators. In synchronous machine, a 3-phase winding is stationary, while the field system is rotating. The fig. 4.31 shows the 3-phase synchronous machine with stationary armature and rotating field system.

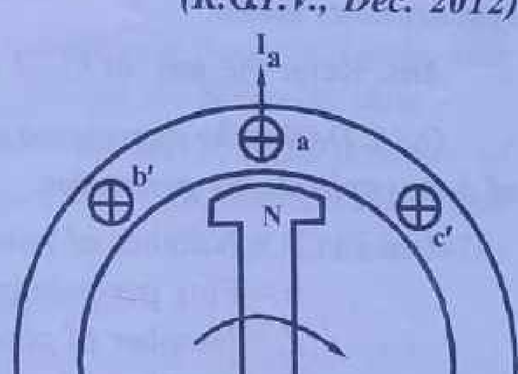


Fig. 4.31

When the field system is moved by an primemover, magnetic flux is induced which cut the conductor of stator. Therefore, an e.m.f., induced in the stator conductor is given by,

$$e = Blv \text{ in volts}$$

where, B = Flux density in tesla

l = Length of stator conductor in metre

v = Speed of conductor in m/s.

where, l and v are constants, thus the induced e.m.f., is directly proportional to the flux density. If the flux density produced by the field winding is sinusoidal the voltage induced in the phase coil will be sinusoidal.

The cylindrical rotor construction synchronous machine is used for two or four poles steam-turbine generators. Hence cylindrical rotor synchronous machine are called ***turbo-alternator.*** The salient pole construction is the most suitable for multi-polar slow-speed water turbine generators. Hence salient pole synchronous generators are called ***hydro-generators.*** Most of the synchronous motors are of the salient-pole type.

The air-gap of the salient pole synchronous machine is gradually increases from the centre to the pole tips. Then a sinusoidal wave of flux density is closely obtained. In case of non-salient pole, the air-gap is more or less uniform. The flux density is obtained by distributing the field winding in several slots. When coils span is made less than the pole pitch, an improved output voltage waveform is obtained.

The frequency is given by

$$f = \frac{PN}{120} \text{ Hz}$$

where, P = Number of poles, N = Synchronous speed.

The standard value of frequency is 50 Hz.

Synchronous speed is the speed at which an alternator must run, in order to generate an e.m.f., of the required frequency.

Q.35. Explain the construction and principle of operation of a synchronous motor. ***(R.G.P.V., Dec. 2015)***

Ans. Refer the ans. of Q.32 and Q.34.

Q.36. Derive the expression of generated e.m.f. equation in the armature of 3-φ synchronous generator. ***(R.G.P.V., Jan./Feb. 2006)***

Ans. Let, P = Number of poles, f = Frequency in Hz

ϕ = Flux per pole in Wb

Z = Number of conductor or coil sides in series per phase

T = Number of coils or turns per phase = Z/2

and, N = Rotor speed in revolution per minute (r.p.m.).

In one revolution of rotor (i.e., 60/N seconds) each stator conductor is cut by a flux ϕP webers

$\therefore$ Change in time, dt = 60/N

Change in flux, $d\phi = \phi P$

$$\therefore \text{ Average e.m.f. induced per conductor} = \frac{d\phi}{dt} = \frac{\phi P}{60/N} = \frac{P\phi N}{60} \text{ volts}$$

$$\text{Average e.m.f. generated per turn} = \frac{2P\phi N}{60}$$

$$\text{Average e.m.f. generated per phase} = \frac{2P\phi N}{60} \times T \text{ volts}$$

But, $N = \dfrac{120\,f}{P} \quad \therefore NP = 120\,f$

$\therefore$ Average e.m.f. induced per phase $= \dfrac{120\,f \times 2\phi}{60} \times T$ volt $= 4f\phi T$ volts

For sinusoidal e.m.f., form factor = 1.11

R.M.S. value of e.m.f./phase = Average value of e.m.f. per phase × Form factor

$= 4f\phi T \times 1.11 = 4.44\,f\phi T$ volts

When the winding is distributed in slots, the above expression must be multiplied by a factor K_b (known as breadth factor or distribution factor). Since the winding are short-pitched, the expression must be multiplied by another factor K_c (known as coil span or pitch factor). Thus the r.m.s. value of induced e.m.f. per phase is given by

$$E = 4.44\,f\phi TK_bK_c = 4.44\,K_w f\phi T$$

where, $K_w = K_b \times K_c$ = Winding factor.

The above equation is the required expression for the e.m.f., induced of rotating electrical machine or synchronous machine. **Proved**

NUMERICAL PROBLEMS

Prob.6. Calculate the no-load terminal voltage of a 3-phase, 4-pole, star connected alternator running at 1500 r.p.m. having the following data –

Sinusoidally distributed flux per pole = 66 mWb, total number of armature slots = 72, number of conductors per slot = 10, distribution factor = 0.96. Assume full pitch winding. ***(R.G.P.V., Feb. 2010)***

Sol. For full pitch winding; coil span factor, $K_c = 1$.

Since distribution factor K_d is given, therefore, it is not to be calculated.

Number of turns per phase,

$$T_{ph} = \frac{72 \times 10}{2 \times 3} = 120$$

Supply frequency, $f = \dfrac{PN_s}{120} = \dfrac{4 \times 1500}{120} = 50$ Hz

E.M.F. induced per phase,

$$E_{ph} = 4.44\,K_cK_d\,f\,\phi\,T_{ph}$$
$$= 4.44 \times 1 \times 0.96 \times 50 \times 66 \times 10^{-3} \times 120 = 1687.9\text{ V}$$

Since the alternator is star connected,

$\therefore$ No load terminal voltage,

$$E_L = \sqrt{3}\,E_{ph} = \sqrt{3} \times 1687.9 = \mathbf{2923.55\ V} \qquad \textbf{Ans.}$$

Prob.7. A synchronous machine has 2-pole, 3-phase, 50 Hz, 2200 V and 36 slots, each slot has two conductor in a double layer winding. The coil pitch is 16 slots. Each phase winding has two parallel paths.

Calculate the flux produced in each pole which is required to generate a phase voltage of 2200 $\sqrt{3}$ V.

Sol. Slots per phase per pole, $m = \dfrac{36}{3 \times 2} = 6$

$$\text{Slot angle} = \frac{2 \times 180^\circ}{\text{Number of slots}} = \frac{2 \times 180^\circ}{36} = 10^\circ$$

$$\text{Coil pitch} = 16 \text{ slots}$$

and $$\text{Pole pitch} = \frac{36}{2} = 18 \text{ slots}$$

Short pitching angle,

$$\theta_{sp} = (18 - 16) \times 10 = 20^\circ$$

$$K_p = \cos\frac{20^\circ}{2} = 0.985$$

$$N_{ph} = \frac{36 \times 2}{2 \times 3 \times 2} = 6$$

and breadth factor, $$K_b = \frac{\sin\dfrac{mY}{2}}{m\sin\dfrac{Y}{2}} = \frac{\sin\left(\dfrac{6 \times 10}{2}\right)}{6\sin\dfrac{10}{2}} = 0.956$$

and, $$E = 4.44\, K_b . K_p . f . \phi . N_{ph}$$

$$\frac{2200}{\sqrt{2}} = 4.44 \times 0.956 \times 0.985 \times 50 \times \phi \times 6$$

$\therefore$ $$\phi = \frac{2200}{\sqrt{2} \times 4.44 \times 0.956 \times 0.985 \times 50 \times 6}$$

$$= \mathbf{1.24\ Wb}$$ **Ans.**

WORKING PRINCIPLE & E.M.F. EQUATION OF 3-PHASE INDUCTION MOTOR, CONCEPT OF SLIP IN 3-PHASE INDUCTION MOTOR, EXPLANATION OF TORQUE-SLIP CHARACTERISTICS OF 3-PHASE INDUCTION MOTOR

Q.37. Write the constructional details of three-phase induction motor.
(R.G.P.V., Jan./Feb. 2008, June 2008)

Ans. A 3-phase induction motor basically consists of a stator and a rotor separated by a uniform air-gap. Since the rotor does not receive electric power by conduction but by induction in exactly the same way as the secondary of a

2-winding transformer and hence it is called ***induction motor.*** The construction of three phase induction motor described as under –

Stator – The stator of a three phase induction motor consists of stator frame, stator core, distributed winding, end-covers, bearings etc. The stator core is built up of sheet steel laminations of 0.4 to 0.5 mm thickness. Laminations are insulated from each other by means of either varnish coating or oxide coating. The laminations are slotted along their inner periphery for housing three phase winding. The stator laminations assembled in a cast iron frame. End-covers are provided for mechanical support to the stator core and it is made of cast iron. Radial ventilating ducts are provided along the length of the stator core, in order to improve the cooling.

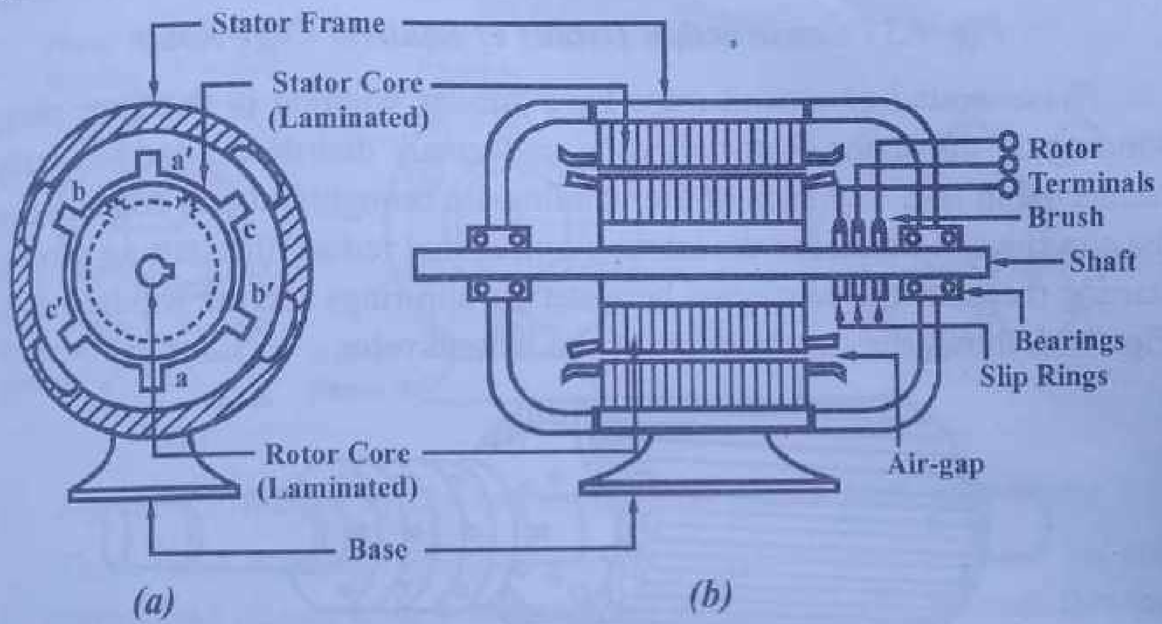


Fig. 4.32 Construction Features of Polyphase Induction Motor

The essential parts of a three phase induction motor are shown in figs. 4.32 (a) and (b). From the fig. 4.32 (a), the stator have 6 slots and 3 coils aa', bb', cc' represents the windings in three phases a, b, c respectively.

Rotor – The induction motor has two types of rotors –

(i) ***Squirrel Cage Rotor*** – Motors using this type of rotor are called ***'squirrel cage induction motors'.***

(ii) ***Phase-wound or Wound Rotor*** – Motors employing this type of rotor are called as ***'slip-ring induction motors'***.

Core of both type of rotor is made of sheet steel laminations which is tightly assembled on the shaft or on the cast iron spider carried by the shaft.

Squirrel cage rotor consists of copper or aluminium bars embedded in the semi-closed slots. Rotor bars are short circuited at each end by solid end rings made of copper, brass or aluminium. It should be noted that the rotor bars are permanently short-cirucuited on themselves, hence it is not possible to add any external resistance in series with the rotor circuit for starting purpose.

Without the rotor core, the rotor bars and end rings look like a cage of squirrel, hence the name ***squirrel cage induction motor***, as shown in fig. 4.33.

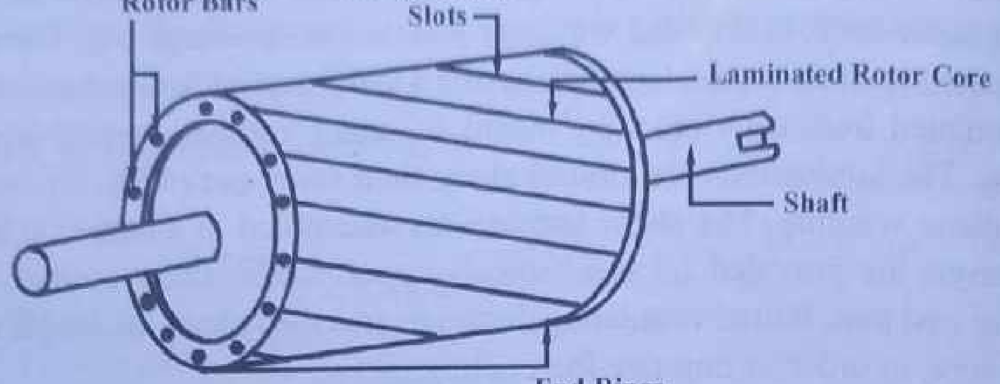


Fig. 4.33 Construction Details of Squirrel Cage Rotor

Phase-wound or wound rotor have similar winding to the three phase winding on the stator. Rotor winding uniformaly distributed and is usually connected in star. The ends of the winding are brought out and connected to the slip rings. To increase the starting torque and reduce the starting current, starting rheostats are connected between the slip-rings and the winding ends. Fig. 4.34 shows the construction of the wound rotor.

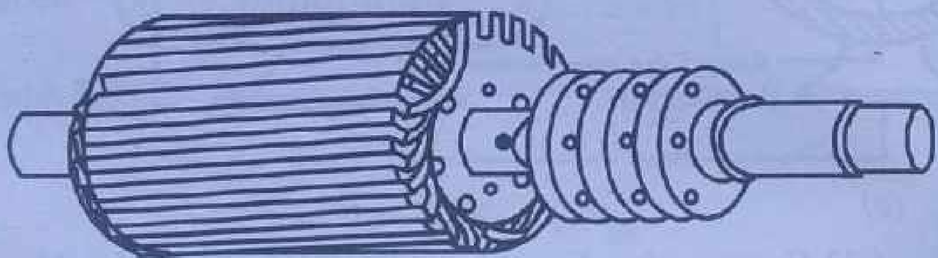


Fig 4.34 Wound Rotor

In both types, the rotor slots are not parallel to the shaft axis i.e., the rotor slots are skewed for obtaining a quicker and smooth operation of the induction motor.

Almost 90 percent of induction motors are squirrel cage type, because this type of motor has simple and most rugged construction and economical, cheap etc.

Q.38. Draw the construction of 3-phase induction machine and synchronous machine. ***(R.G.P.V., June 2014)***

Ans. Refer the ans. of Q.37 and Q.32.

Q.39. Explain the concept of rotating magnetic field in a 3-phase induction motor. ***(R.G.P.V., Dec. 2010)***

Or

Explain working principle of a 3-ϕ induction motor.

(R.G.P.V., May 2018)

Or

Discuss the working principle of 3-phase induction motor.

(R.G.P.V., Nov. 2018)

Ans. A rotating magnetic field is produced by the flow of balanced polyphase currents through polyphase winding. All polyphase A.C. machines work on the principle of rotating magnetic field. Three-phase induction machine is one of them which produces the rotating magnetic field, because of balanced three-phase currents, three-phase winding are considered.

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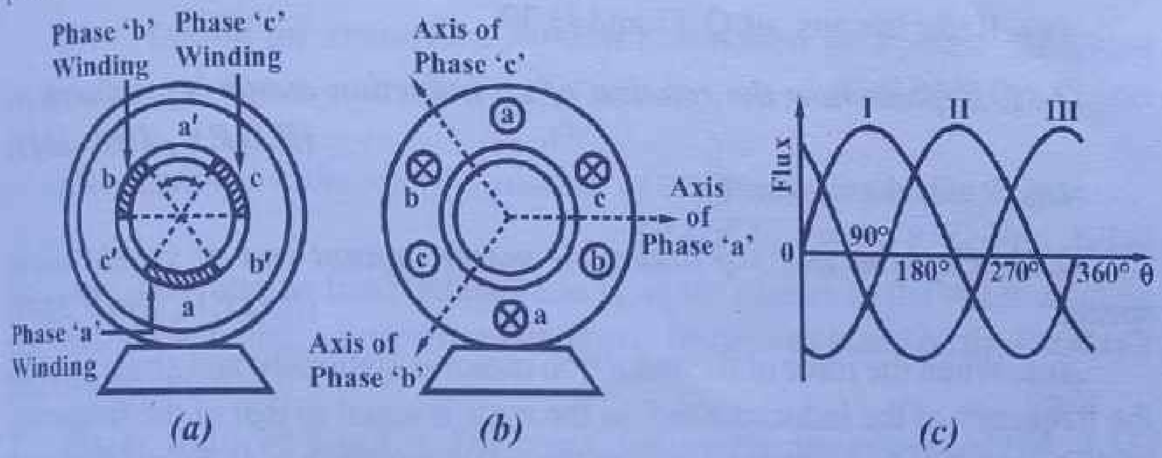

Fig. 4.35 Principle of Operation of Three-phase Induction Motor

These three windings are shown by three full pitched coils aa', bb' and cc' representing phases a, b, c respectively in fig. 4.35 (b). Current flowing through each phase winding, establishes the magnetic flux direct along its magnetic axis. The direction of the current is assumed to be positive as indicated by crosses in the coil sides a, b, c hence when phase 'a' alone carries positive currents, the flux produced by this phase direct horizontally from left to right. The direction of the flux is reversed i.e., from right to left, if the current in phase 'a' is negative.

The resultant flux in the air-gap is due to the combined action of all the winding fluxes, which is rotating with the speed given by,

$$N_s = \frac{120\,f}{P} \text{ revolution/minute}$$

where, f = Frequency, in Hz

P = Number of poles in machines

N_s = Synchronous speed in r.p.m.

A 3-phase induction machine is a single excited A.C. machine. Its stator winding is directly connected to A.C. source, whereas its rotor winding receives its energy by means of induction.

Without the rotor core, the rotor bars and end rings look like a cage of squirrel, hence the name ***squirrel cage induction motor***, as shown in fig. 4.33.

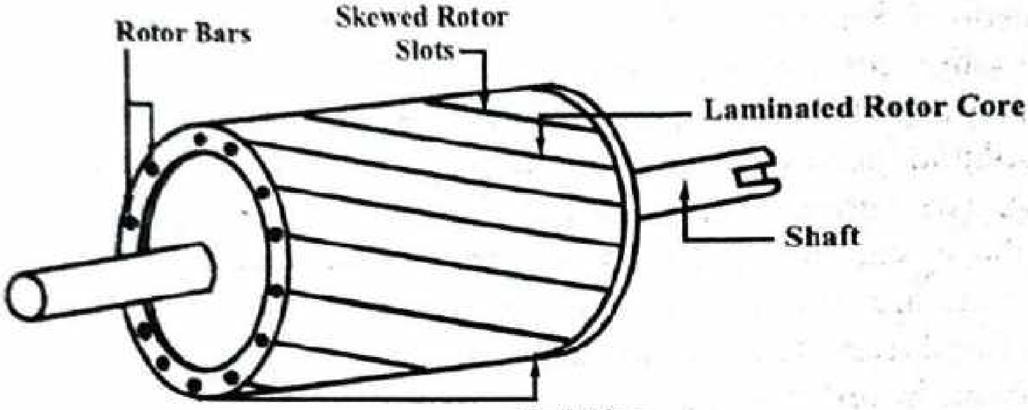

Fig. 4.33 Construction Details of Squirrel Cage Rotor

Phase-wound or wound rotor have similar winding to the three phase winding on the stator. Rotor winding uniformaly distributed and is usually connected in star. The ends of the winding are brought out and connected to the slip rings. To increase the starting torque and reduce the starting current, starting rheostats are connected between the slip-rings and the winding ends. Fig. 4.34 shows the construction of the wound rotor.

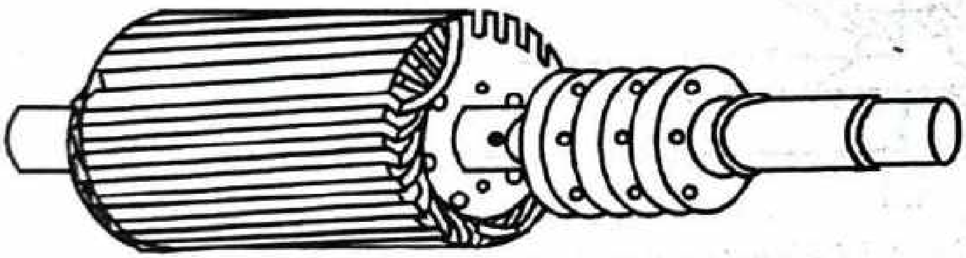

Fig 4.34 Wound Rotor

In both types, the rotor slots are not parallel to the shaft axis i.e., the rotor slots are skewed for obtaining a quicker and smooth operation of the induction motor.

Almost 90 percent of induction motors are squirrel cage type, because this type of motor has simple and most rugged construction and economical, cheap etc.

Q.38. Draw the construction of 3-phase induction machine and synchronous machine. ***(R.G.P.V., June 2014)***

Ans. Refer the ans. of Q.37 and Q.32.

Q.39. Explain the concept of rotating magnetic field in a 3-phase induction motor. ***(R.G.P.V., Dec. 2010)***

Or

Explain working principle of a 3-ϕ induction motor.

(R.G.P.V., May 2018)

Or

Discuss the working principle of 3-phase induction motor.

(R.G.P.V., Nov. 2018)

Ans. A rotating magnetic field is produced by the flow of balanced polyphase currents through polyphase winding. All polyphase A.C. machines work on the principle of rotating magnetic field. Three-phase induction machine is one of them which produces the rotating magnetic field, because of balanced three-phase currents, three-phase winding are considered.

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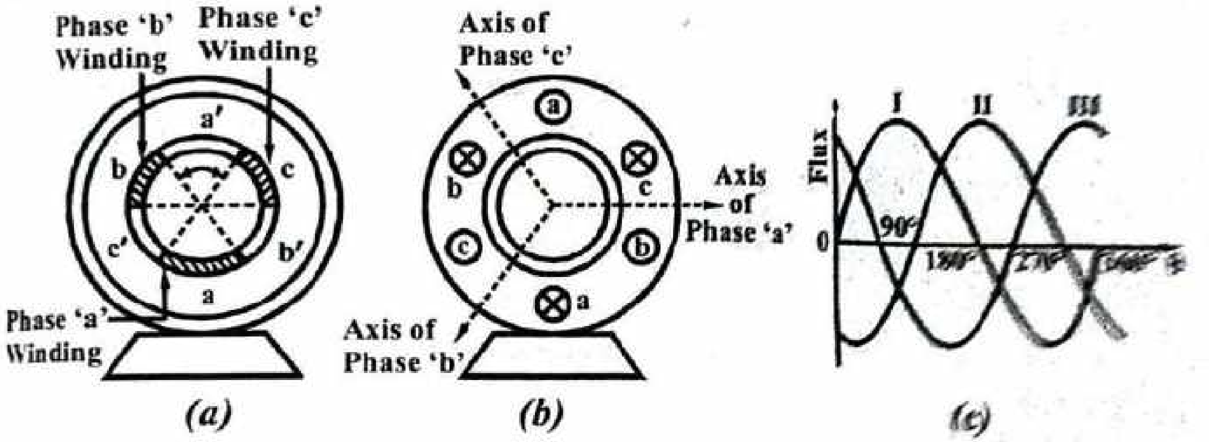

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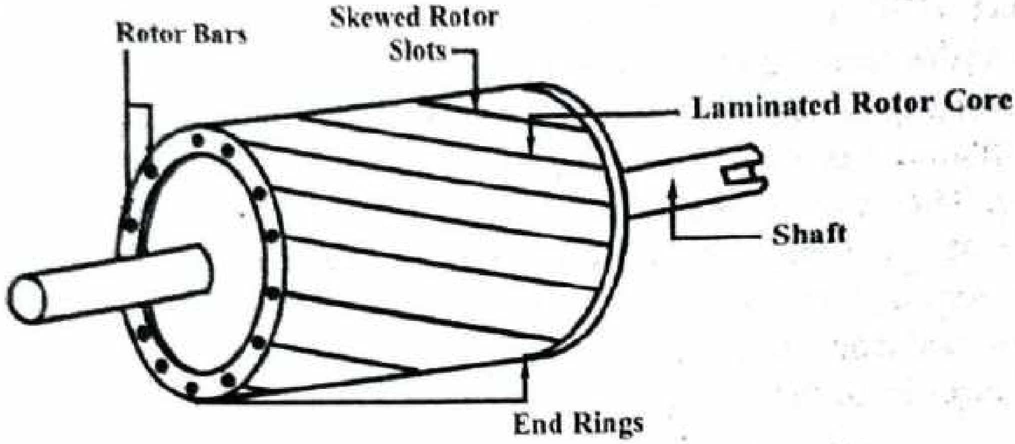

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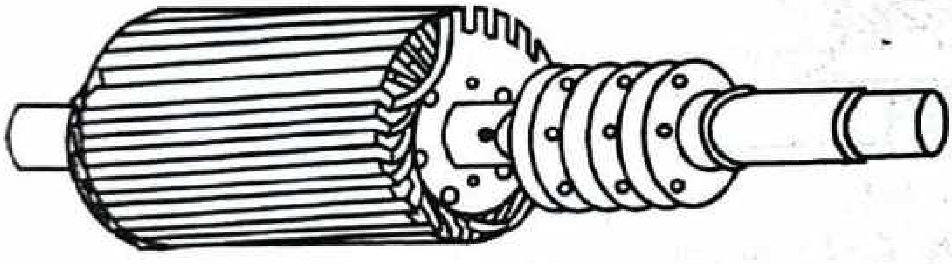

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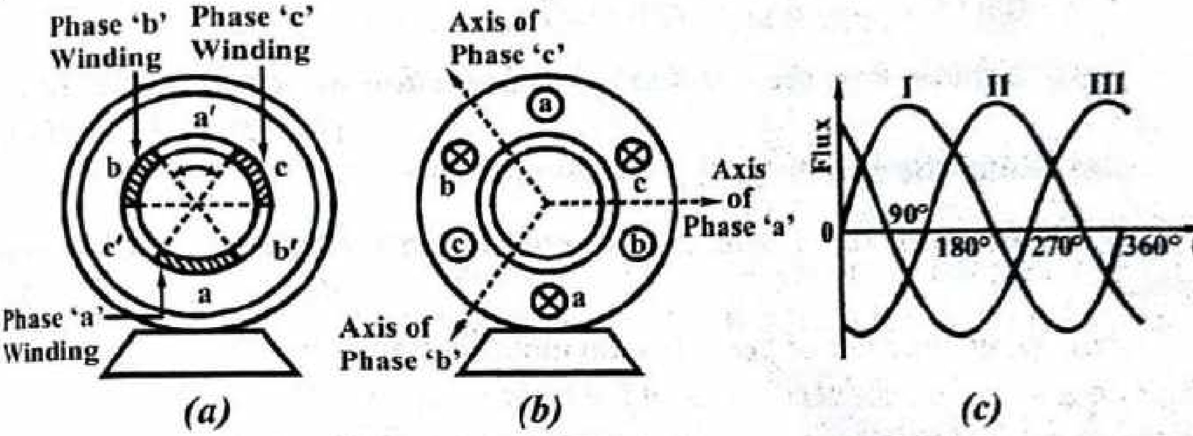

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P = Number of poles in machines
N_s = Synchronous speed in r.p.m.

A 3-phase induction machine is a single excited A.C. machine. Its stator winding is directly connected to A.C. source, whereas its rotor winding receives its energy by means of induction.

Principle of Operation – When 3-ϕ supply is fed to the stator winding of a 3-ϕ induction motor, a magnetic field is produced in the stator, which rotates at synchronous speed. The lines of force of stator conductors because of relative motion between the field and the rotor conductor. The rotor winding is equal to the short circuited winding such as e.m.f. generated in the rotor conductor circulates a current. The interaction of stator magnetic field and rotor current carrying conductors causes a force upon rotor conductors tending to rotate in the direction of rotor flux. Thus, the torque will be produced, only when the speed of the rotor is some what less than synchronous speed.

Q.40. Explain construction and working principle of three phase induction motor. ***(R.G.P.V., Dec. 2016)***

Ans. Refer the ans. of Q.37 and Q.39.

Q.41. Explain how the rotation of an induction motor is produced ? ***(R.G.P.V., Dec. 2015)***

Ans. Refer the ans. of Q.39.

Q.42. Explain, the 3-ϕ induction motor cannot run at synchronous speed. ***(R.G.P.V., April 2009)***

Ans. When the rotor of the induction motor is stationary and about to start, the frequency of the induced e.m.f. in the rotor is equal to that of the frequency of the supply fed to the stator, because the relative motion is at the synchronous speed. As the rotor picks up the speed, the relative motion between the rotor and the synchronously rotating magnetic field becomes less and the frequency of the generated e.m.f. falls. The magnitude of the rotor generated e.m.f., induced rotor current and torque depends upon the relative motion. In case the relative motion is zero, i.e., rotor runs at synchronous speed, there would be no induced e.m.f., no current and hence no torque. Thus, the rotor of a 3-phase induction motor can never run at synchronous speed, it is known as asynchronous machine. Even on no-load, the speed of the rotor must be somewhat less than synchronous speed, because a torque must be produced to overcome the friction, windage and iron losses. When the motor is loaded, the speed of the rotor falls which causes an increase in the relative motion, thus increasing the magnitude of induced e.m.f., rotor current and the torque in order to cope with increased load.

Q.43. Answer the following w.r.t. induction motor

(i) What is the frequency of rotor currents of an induction motor ?

(ii) Why is an induction motor called asynchronous ?

(R.G.P.V., June 2013)

Ans. (i) Frequency of Rotor Currents – The frequency of rotor currents depends upon the relative speed between rotor and stator field. When the rotor is stationary, the frequency of rotor currents is the same as that of the supply

frequency. But once the rotor starts rotating, the frequency of rotor currents depends upon slip speed $(N_s - N)$. Let at any speed N, the frequency of rotor currents be frequency then

$$F_r = \frac{(N_s - N)P}{120} = \frac{(N_s - N)}{N_s} \times \frac{N_s P}{120}$$

$$F_r = s \times F \qquad ...(i)$$

where $s = \dfrac{N_s - N}{N_s}$ and $F = \dfrac{N_s P}{120}$

(ii) Why Induction Motor called Asynchronous – Refer the ans. of Q.42.

Q.44. Obtain an expression for e.m.f. equation of 3-phase induction motor. ***(R.G.P.V., Dec. 2011)***

Or

Develop/Derive the e.m.f. equation of a 3-phase induction motor. ***(R.G.P.V., June 2014, Dec. 2014)***

Ans. The rotating field induces e.m.fs. in the phases of the stator winding and the rotor winding, whose expressions may be derived based on the Faraday's law of induction.

Stator Induced e.m.f. – The e.m.f. induced in the phase aa' (fig. 4.35) of the stator winding is given by

Induced e.m.f. in phase a, $e_a = \dfrac{-d\psi_a}{dt}$ ...(i)

where, ψ_a is the linkages flux of the coil aa', which varies as the cosine of the angle ωt, and can be defined in terms of air gap flux per pole, ϕ and the number of turns per phase, T_{1ph} in the coil aa'.

Thus, the linkage flux, $\psi_a(\omega t) = T_{1ph}\,\phi \cos \omega t$ ...(ii)

Putting equation (ii) into equation (i), we have

Induced e.m.f. in phase a, $e_a = \dfrac{-d}{dt}(T_{1ph}\phi \cos \omega t) = \omega T_{1ph}\phi \sin \omega t$

or

$$e_a = E_{max} \sin \omega t \qquad ...(iii)$$

Similarly, induced e.m.f. in phase b, $e_b = E_{max} \sin(\omega t - 120°)$ ...(iv)

and Induced e.m.f. in phase c, $e_c = E_{max} \sin(\omega t - 240°)$ ...(v)

where the maximum induced e.m.f.s. $E_{max} = \omega T_{1ph}\,\phi$

Thus, the r.m.s. value of the induced e.m.f. per phase

$$= \frac{E_{max}}{\sqrt{2}} = \frac{\omega T_{1ph}\phi}{\sqrt{2}} = \frac{2\pi f T_{1ph}\phi}{\sqrt{2}}$$

or induced e.m.f. per phase (r.m.s.), $E_{ph} = 4.44 f\, T_{1ph}\phi$ ...(vi)

Hence, the resultant e.m.f. is always less than the arithmetic sum of the separate e.m.fs. The ratio of the resultant e.m.f. to the arithmetic sum of separate e.m.fs. is called the distribution factor and is denoted by k_d. However, stator coils may be short pitched which again reduces by resultant e.m.f. by a factor, k_c, known as coil span factor.

Taking into account the above two effects, k_w ($k_w = k_d k_c$) known as the winding factor, the r.m.s. value of induced e.m.f. per phase modifies to,

Induced e.m.f. per phase, $E_{1ph} = 4.44 f T_{1ph} \phi k_w$ ...(vii)

Rotor Induced e.m.f. – The rotating field generated in the air gap due to stator currents also induces e.m.f. in the rotor winding, which is given by,

Rotor induced e.m.f. per phase,

$$E_{2ph} = 4.44\, f_r\, T_{2ph}\, \phi k_{wr} \quad ...(viii)$$

where, f_r = Frequency of rotor induced e.m.f.

T_{2ph} = Number of turns per phase in the rotor winding

k_{wr} = Winding factor of the rotor winding.

Q.45. Define the term slip.

Ans. The slip is defined as the speed of the rotor relative to the rotating magnetic field produced in the stator.

Let, N_s = Synchronous speed of the rotating magnetic field in r.p.m.

N = Speed of the rotor in r.p.m.

Then, $$\text{Slip, } s = \frac{N_s - N}{N_s} = \left(1 - \frac{N}{N_s}\right)$$

Q.46. Define the term slip-frequency.

Ans. The speed at which the rotor conductors are cut by the rotating magnetic field is $(N_s - N)$ r.p.m. is also known as slip speed. Frequency, corresponding to this speed is called the slip-frequency.

$$\text{Slip frequency, } f_r = \frac{P}{120}(N_s - N)$$

Q.47. Compare induction machine and synchronous machine on the basis of construction and applications. (R.G.P.V., June 2017, Dec. 2017)

Or

Differentiate between induction machine and synchronous machine. (R.G.P.V., Nov. 2018)

Ans. The comparison between three-phase synchronous and induction motors are as follows –

S.No.	Synchronous Motor	Induction Motor
(i)	A synchronous motor is a doubly excited machine. Its field winding is energised from a D.C. source and its armature winding from an A.C. source.	An induction motor is a singly-excited machine. Its stator winding is energised from an A.C. source.
(ii)	It is operated under wide range of power factors, both lagging and leading by changing its excitation.	An induction motor operates at only lagging power factor, which becomes very poor at high loads.
(iii)	A synchronous motor can be used for power factor correction in addition to supplying torque to drive mechanical loads.	An induction motor is used for driving mechanical loads only.
(iv)	It always runs at synchronous speed. The speed is independent of load.	Its speed falls with the increase in load and is always less than the synchronous speed.
(v)	It is not self-starting. It has to be run upto synchronous speed by some means before it can be synchronised to A.C. supply.	An induction motor has got self-starting torque.
(vi)	It is costlier than an induction motor of the same output and voltage rating.	It is cheaper than a synchronous motor of the same output and voltage rating.
(vii)	A synchronous motor is more efficient than induction motor of of the same output and voltage rating.	An induction motor is less efficient than synchronous motor of the same output and voltage rating.

Q.48. Sketch the torque-speed (T-N) characteristic of an induction motor. Show the quantity on each axis. Show on this graph –

(i) Synchronous speed ***(ii) Actual speed at small slip***

(iii) Starting torque ***(iv) Pull out torque***

(v) Slip speed.

Why does the speed of an induction motor fall on loading ?

(R.G.P.V., Dec. 2002)

Ans. Fig. 4.36 shows the position of various parameters on torque-speed characteristic curve of a 3-ϕ induction motor.

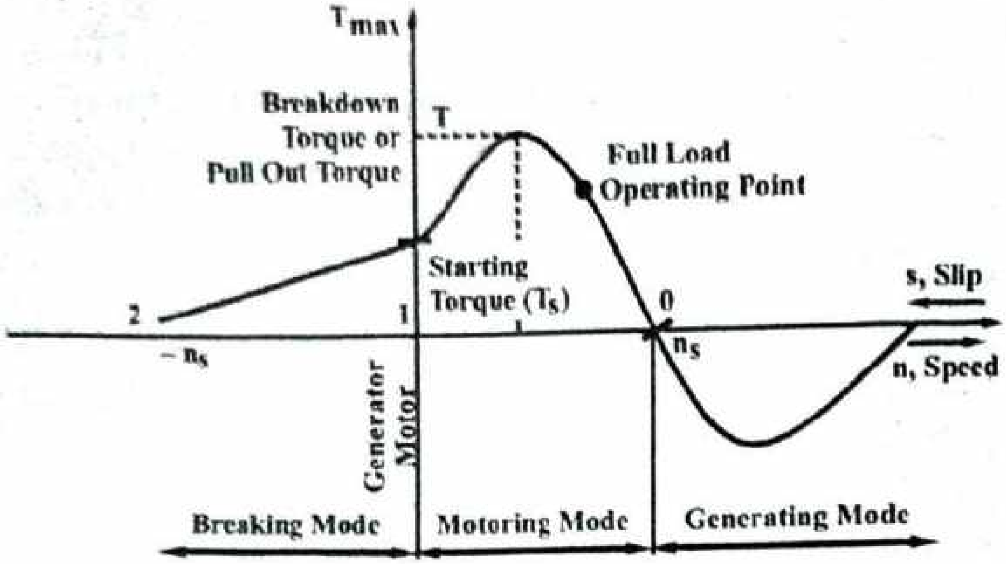


Fig. 4.36 Torque-speed Characteristic of a 3-ϕ Induction Motor

When the induction machine is loaded, the ficticious load increases due to which slip of the motor increase and the speed decreases.

Q.49. Explain torque-slip characteristics of a 3-phase induction motor. ***(R.G.P.V., Dec. 2012)***

Or

Draw and explain the complete torque-slip characteristic of three-phase induction motor. ***(R.G.P.V., Dec. 2013, 2014)***

Ans. Since we know that, torque T is given by

$$T = k_1 \frac{sR_2E_2^2}{R_2^2 + (sX_2)^2}$$

From the above equation, it can be said that –

(i) When slip s is zero, the torque T is also zero, so the slip-torque curve starts from origin.

(ii) When slip s is very low, T is approximately proportional to s for fixed R_2.

Thus slip-torque curves are straight lines.

(iii) As the slip s increases, torque T increases, reaches its maximum value when slip, $s = \frac{R_2}{X_2}$.

(iv) With further increase in slip, the torque T begins to decrease. The result is that the motor slows down and even stops at that condition. Hence the motor operates for the slip in between zero and that corresponding to maximum torque. With higher the value of slip R_2 becomes negligible as compared to sX_2 and the torque varies inversely with slip. It means that slip-torque curve is a rectangular hyperbola.

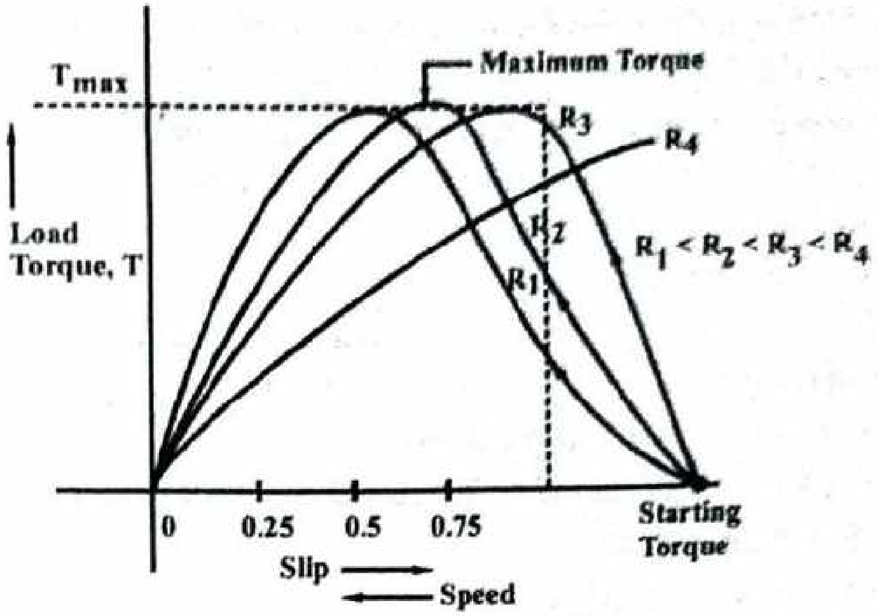


Fig. 4.37 Slip-torque Characteristic Curve for 3-ϕ Induction Motor

Q.50. Draw torque-slip characteristics of three phase induction motor and explain its stable and unstable region of operation. (R.G.P.V., June 2013)

Ans. **Torque-slip Characteristics** – Refer the ans. of Q.49.

The torque-speed curve of an induction motor is shown in fig. 4.38. Therefore, induction motor develops the same torque at point X and Y. However at point X the motor is unstable because with the increase in load speed decrease and the torque developed by the motor also decreases. Hence, the motor could not pick up the load and the result is that the motor slows down and eventually stops. The miniature circuit breakers will be tripped open when the circuit has been so protected.

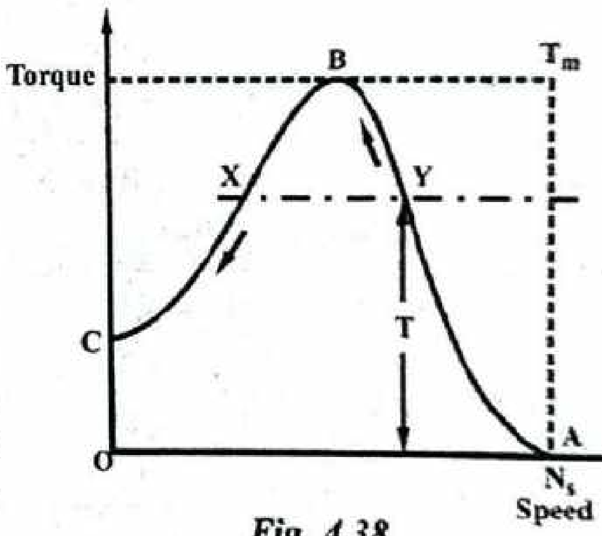


Fig. 4.38

At point Y, the motor is stable because in this region with the increase in load speed decreases but the torque produced by the motor increases. Thus the motor will be in position to pick up the extra load effectively.

Therefore, on the torque-speed curve region BC is the unstable region and region AB is the stable or operating region of the induction motor as shown in fig. 4.38.

Q.51. Draw torque-slip characteristics of a 3-phase induction motor. Explain the concept of slip. (R.G.P.V., June 2012)

Ans. Refer the ans. of Q.49 and Q.45.

Q.52. Derive an expression for torque developed in a 3-ϕ induction motor and also derive the condition for maximum starting torque.

Ans. Consider a pully of radius r metre acted upon by a circumferencial force of F newton, which cause it to rotate at N r.p.m.

Then torque, $T = F \times r$ in N-m

Work done by this force in one revolution,

$$= \text{Force} \times \text{Distance} = F \times 2\pi r \text{ in joule}$$

Power developed $= F \times 2\pi r \times N = F \times r \times 2\pi N = T.\omega$ in watt

We know that, for any electrical machine,

Mechanical power developed = Electrical power developed

For an induction machine –

Electrical power = $mE_2I_2 \cos \phi_2$

where, m = Number of phases

E_2 = Rotor e.m.f. per phase at standstill

I_2 = Rotor current

ϕ_2 = Angle between rotor e.m.f. and current.

For a three-phase induction machine –

$$T\omega = 3\, E_2I_2 \cos \phi_2$$

$$T = \frac{3}{2\pi N_s}.E_2I_2 \cos \phi_2$$

If, R_2 = Rotor resistance/phase

X_2 = Rotor reactance/phase

and, $Z_2 = \sqrt{R_2^2 + X_2^2}$

then $\cos \phi_2 = \dfrac{R_2}{Z_2} = \dfrac{R_2}{\sqrt{R_2^2 + X_2^2}}$ and, $I_2 = \dfrac{E_2}{Z_2} = \dfrac{E_2}{\sqrt{R_2^2 + X_2^2}}$

Starting torque, $(T_{st}) = \dfrac{3}{2\pi N_s} E_2I_2 \cos \phi_2$

or $$T_{st} = \frac{3}{2\pi N_s}.E_2.\frac{E_2}{\sqrt{R_2^2 + X_2^2}}.\frac{R_2}{\sqrt{(R_2^2 + X_2^2)}} = \frac{3}{2\pi N_s}.\frac{E_2^2 R_2}{(R_2^2 + X_2^2)}$$

Condition for maximum starting torque –

$$T_{st} = \frac{3E_2^2}{2\pi N_s}.\frac{R_2}{(R_2^2 + X_2^2)}$$

Let, $k = \dfrac{3E_2^2}{2\pi N_s}$

$$\therefore \quad T_{st} = k\frac{R_2}{R_2^2 + X_2^2} \text{ and } \frac{d}{dR_2}T_{st} = k\left[\frac{1}{\left(R_2^2 + X_2^2\right)} - \frac{R_2(2R_2)}{\left(R_2^2 + X_2^2\right)^2}\right] = 0$$

or $R_2^2 + X_2^2 = 2R_2^2$ or $\mathbf{R_2 = X_2}$

Hence, starting torque will be maximum when rotor resistance equal to rotor reactance.

Torque Under Running Condition –

Let, E_r = Rotor e.m.f./phase under running condition

I_r = Rotor current/phase under running condition.

Now $E_r = sE_2$

$$I_r = \frac{E_r}{Z_r} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}} \text{ and } \cos\phi_r = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Torque in running condition,

$$T \propto E_r I_r \cos\phi_r \quad \text{or} \quad T = k_1\frac{sE_2^2R_2}{R_2^2 + (sX_2)^2}$$

where, $k_1 = \dfrac{3}{2\pi N_s}$

Condition for Maximum Torque Under Running Condition –

Under running condition,

$$T = \frac{k_1 sE_2^2R_2}{R_2^2 + (sX_2)^2}$$

The condition for maximum torque can be obtained by differentiating torque with respect to slips.

$$\therefore \quad \frac{dT}{ds} = \frac{d}{ds}\left[k_1\frac{sE_2^2R_2}{\left\{R_2^2 + (sX_2)^2\right\}}\right] = 0$$

or $$R_2^2 = s^2X_2^2 \text{ or } R_2 = sX_2 \text{ or } s = \frac{R_2}{X_2}$$

$$\therefore \quad T_{max} = k_1\frac{(R_2/X_2)E_2^2R_2}{R_2^2 + \left(\frac{R_2}{X_2}\right)^2 .X_2^2} = k_1\frac{E_2^2}{2X_2}$$

or $$T_{max} = \frac{3}{2\pi N_s}.\frac{E_2^2}{2X_2} = \frac{3E_2^2}{4\pi N_s X_2}$$

Q.53. Draw the torque-slip characteristics of an induction motor. Develop necessary condition for maximum torque. ***(R.G.P.V., June 2014)***

Ans. Refer the ans. of Q.49 and Q.52.

NUMERICAL PROBLEMS

Prob.8. A 3-phase induction motor has 6-poles and runs at 960 r.p.m. on full load. It is supplied from an alternator having 4 poles and running at 1500 r.p.m. Calculate the full-load slip of the induction motor.

(R.G.P.V., June 2009, 2012)

Sol. First, we calculate supply frequency which is supplied from alternator to induction motor.

$$f = \frac{N_{sa} \times P_a}{120} = \frac{1500 \times 4}{120} = 50 \text{ Hz}$$

(N_{sa} = Synchronous speed of alternator, P_a = Number of poles in alternator)

Calculation for induction motor,

$P = 6$ poles

$f = 50$ Hz (supplied frequency)

$N = 960$ r.p.m. (rotor speed)

We know that, synchronous speed of induction motor is given by

$$N_s = \frac{120 f}{P}$$

Now putting the values of P and f, we get

$$N_s = \frac{120 \times 50}{6} = 1000 \text{ r.p.m.}$$

We know that, percentage slip is given as

$$s = \frac{N_s - N}{N_s} \times 100 = \frac{1000 - 960}{1000} \times 100 = \mathbf{4\% \text{ or } 0.04} \qquad \textbf{Ans.}$$

Prob.9. A three phase 440 volt, 50 hp, 50 Hz induction motor delivers rated output power at 1440 r.p.m. Find

(i) No. of poles of machine

(ii) Synchronous speed

(iii) Slip

(iv) Slip r.p.m.

(v) Rotor speed w.r.t.

(a) Rotor structure (b) Stator.

(vi) Rotor e.m.f. at operating speed if stator to rotor turn ratio is 1 : 0.5. Assume winding factor is unity.

(R.G.P.V., Dec. 2012)

Sol. Here, $f_1 = 50$ Hz

(i) Number of poles of machine

$$P = \frac{120 f_1}{N} = \frac{120 \times 50}{1440} = 4.2 = \mathbf{4\ poles}$$

(ii) Synchronous speed

$$N_s = \frac{120 f_1}{P} = \frac{120 \times 50}{4} = \mathbf{1500\ r.p.m.}$$

(iii) Slip, $$s = \frac{N_s - N}{N_s} = \frac{1500 - 1440}{1500} = \mathbf{0.04}$$

Rotor frequency $f_2 = sf_1 = 0.04 \times 50 = 2$ Hz

(iv) Slip speed in r.p.m.

$$= N_s - N = 1500 - 1440 = \mathbf{60\ r.p.m.}$$ **Ans.**

(v) Rotor speed w.r.t. –

(a) Rotor structure $= \dfrac{120 \times (\text{Rotor frequency})}{\text{Poles}} = \dfrac{120 \times 2}{4}$

$= \mathbf{60\ r.p.m.}$ **Ans.**

(b) Stator structure = (Mechanical speed of rotor) + Speed of rotor w.r.t. rotor structure)

$= 1440 + 60 = \mathbf{1500\ r.p.m.}$ **Ans.**

(vi) $$\frac{E_1}{E_{LS}} = \frac{4.44 k_{w_1} f_1 \phi T_1}{4.44 k_{w_2} s f_2 \phi T_2}$$

where $k_{w_1} = k_{w_2}$ = winding factor = 1

$$\frac{E_1}{E_2} = \frac{T_1}{T_2} = \frac{1}{0.5}$$

Prob.10. The core loss in a 3-phase induction motor is 100 W and equals the mechanical loss, stator copper loss is 150 W. When developing 2000 watts as the shaft power. What is the efficiency of the machine ? Assume the slip as 4%. ***(R.G.P.V., Dec. 2004, 2017)***

Sol. Here, given

Core loss is 100 W = Mechanical loss

Stator copper loss is 150 W

Shaft output (power) = 2000 watts (W)

Rotor copper losses = Slip × Rotor input

= 0.04 (2000 + 100 + 150)

Hence rotor copper losses = 90 W

Stator input = Gross output + Mechanical loss + Stator Cu loss

= 2000 + 100 + 150 + 90 = 2340 watts

$$\text{Efficiency of a machine} = \frac{\text{Motor output}}{\text{Motor input}}$$

$$\eta\% = \frac{2000}{2340} \times 100 = 0.855 \times 100 = \mathbf{85.5\%} \qquad \textbf{Ans.}$$

TYPES OF LOSSES OCCURRING IN ELECTRICAL MACHINES, APPLICATIONS OF D.C. MACHINE, INDUCTION MACHINE AND SYNCHRONOUS MACHINE

Q.54. What are the common losses in a rotating machine and on what factors do they depends ? (R.G.P.V., Jan./Feb. 2007, Nov./Dec. 2007)

Or

Enumerate the various types of losses occurring in electrical machines. (R.G.P.V., Dec. 2015)

Or

Discuss various types of losses occurs in various electrical machines. (R.G.P.V., June 2016)

Or

Write short note on losses in electrical machines. (R.G.P.V., Nov. 2018)

Ans. Various losses in an electric machine are enumerated and elaborated as follows –

Constant Losses – These losses remain constant for a, machine operated at constant mains voltage and run at substantially constant speed. These losses can be subdivided into two components.

(i) Mechanical Loss – These comprise brush friction, bearing friction and windage and ventilation system losses and are substantially constant for small variation in speed.

(ii) No-load Core (Iron) Loss – These losses have their origin in hysteresis and eddy current phenomena. In a transformer, these arise due to fixed direction alternating flux. In machine, these losses are caused by fixed flux distribution (north-south) in which the rotor moves as in the armature of a D.C. machine or rotating flux distribution that sweeps through the stator as in the armature (stator) of a synchronous machine or the stator of an induction machine. The flux density in such a member oscillates in both magnetide and direction resulting in much higher loss density then in transformer. It is to be noted here that the frequency of flux variation and axis rotation is very low in the rotor of an induction machine and therefore these kinds of losses in that member are small enough to be ignored.

Because of slotting, high frequency flux density oscillation takes place the slotted member and even in the main pole of the D.C. machine due to the effect of armature slotting [$f_{slot} = (25/P)f$]. The associated loss is known as pulsation loss.

Variable losses are of two types given below –

(i) ***Copper (I^2R) Loss*** – These are field and armature winding ohmic losses and are computed with D.C. resistance of winding at 75°C. Field copper loss for D.C. and synchronous machines is constant for given excitation and can therefore be lumped with constant losses.

The voltage drop at D.C. machine brushes is fixed coefficient the order of 1-2 V as the conduction process is mainly by the short, ionized gaps rather than by physical constant. Therefore strictly speeding brush contact loss is directly proportional to the armature current.

(ii) Stray-load Loss – Under condition of load, the flux density wave undergoes distortion. This lead to load dependent losses in armature teeth.

Also when the armature conductors carry load current this is not uniformly distributed over the conductor cross-section being an alternating current, thereby increasing the effective conductor resistance.

These low losses components together are known as ***stray-load loss.***

Q.55. Specify the application of following motors in field –
(i) Three phase induction motor (ii) Synchronous motor
(iii) D.C. motors (iv)Single phase induction motor.
(R.G.P.V., June 2012)

Ans. (i) Three Phase Induction Motor – Three phase induction motor can be used in the following fields –

(a) A wound rotor induction motor is used for loads requiring severe starting condition or for loads requiring speed control.

(b) A wound rotor motor, also called slip ring motor, may be used for hoists, cranes, elevators, compressors etc.

(c) A squirrel cage motor with low rotor resistance is used for fans, centrifugal pumps, most machinery tools, wood-working tools etc.

(d) A squirrel cage motor with high rotor resistance is used for compressors, crushers, reciprocating pumps.

(e) A squirrel cage motor with very high resistance are used for intermittent load like punching press, shears, hoists, elevators etc.

(ii) Synchronous Motor – Synchronous motor can be used in the following fields –

(a) The 3-phase synchronous motor is used when a prime mover having a constant speed from no-load condition to full load is required, suc as fans, air compressors, and pump.

(b) The synchronous motor is used in some industrial applications to drive a mechanical load and also to correct the power factor.

(iii) D.C. Motors – Different types of D.C. motors used in different field's such as –

(a) Separately Excited Motors – These motors are used in steel rolling mills, paper machines, diesel, electric propulsion of ships etc.

(b) Series Motor – This type of motor are suitable for electric traction, cranes, elevators, vaccum cleaners, hari driers, fans and air compressors etc.

(c) Shunt Motors – This type of motor useful for industrial drives such as lathes, drills, grinders, shapers, spinning etc.

(d) Compound Motors – The cumulative compound motors are best suited for punching and shearing machines, rolling mills, lifts and mine-hoists etc.

(iv) Single Phase Induction Motor – Single-phase induction motor 1-ϕ I.M. can be used in the following devices –

(a) Sewing machines (b) Vacuum cleaners (c) Food mixers and blenders (d) Hair driers (e) Electric shavers (f) Saws (g) Projectors (h) Portable power tools like drills.

Q.56. Give the applications of D.C. generator.

Ans. Self excited generators are used for maintaining constant terminal voltage.

(i) In dynamometer (for measuring torque)

(ii) D.C. welding generators

(iii) Control type D.C. generator for closed loop system

(iv) Techogenerators.

Separately excited generators are used for wide output voltage control, some applications are –

(i) To serve as an excitation source for large alternators in power generating stations.

(ii) To serve as a control generator in Ward-Leonard system of speed control.

(iii) Used as auxiliary and emergency power supplies.

●●

UNIT 5

BASIC ELECTRONICS

NUMBER SYSTEMS & THEIR CONVERSION USED IN DIGITAL ELECTRONICS

Q.1. What do you mean by number system ?

Ans. Generally in any number system there is an ordered set of symbols called digits, which are used to specify any number. The digits are defined for performing arithmetic operations, such as addition, subtraction, multiplication, etc. A collection of these digits forms a number, which in general has two parts, namely integer and fractional. These two parts are set apart by a radix point (.).

Q.2. What do you mean by MSB and LSB ?

Ans. In any number representation, the left most digit, which has the large positional weight out of all the digits shown in that number is known as the most significant bit (MSB) and the right most digit, which has least positional weight out of all the digits present in that number is known as the least significant bit (LSB).

Q.3. What is the principle of positional weighting ?

Ans. The principle of positional weighting can be extended to any number system. Any number can be represented by the equation

$$Y = d_n r^n + d_{n-1} r^{n-1} + ... + d_1 r^1 + d_0 r^0$$

where Y is the value of the entire number, d_n is the value of the n^{th} digit from the point and r is the radix or base. This equation has already been applied to the different number system.

Q.4. Explain number systems used in digital electronics.

(R.G.P.V., Dec. 2014)

Ans. Generally, four types of number systems are used in digital electronics as –

(i) Binary Number System – It is a positional weighted system. The base of this number system is 2. Only two symbols, namely 0 and 1 are used

in this system. These are called ***bits***. The binary number consists of a sequence of bits, each of which is either 0 or 1. In the binary number system, a group of four bits is called ***nibble*** and a group of 8-bits is called ***byte***.

(ii) Octal Number System – The octal number system is also positional weighted system. The octal number system uses the digits 0, 1, 2, 3, 4, 5, 6 and 7. The base of this system is eight (8). Since its base $8 = 2^3$, every 3-bit group of binary can be represented by an octal digit. The least significant position has weight of 8^0, i.e., 1, the higher significant positions are given weights in the ascending powers of eight (8), i.e., 8^1, 8^2, 8^3, etc., respectively.

(iii) Decimal Number System – It is a positional weighted system, which means that the value attached to a symbol depends on its location with respect to the decimal point.

The decimal number system contains ten unique symbols, 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9. Since counting in decimal involves ten symbols, its base is ten. The digits to the right of decimal point have weights, which are negative powers of 10 and forms fractional part. The digits to the left of the decimal point have weights, which are positive powers of 10 and forms integer part.

(iv) Hexadecimal Number System – The base of hexadecimal number system is 16, i.e., it has 16 independent symbols. These 16 symbols are namely 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E and F. Since its base is $16 = 2^4$, every 4 binary digit combination can be represented by one hexadecimal digit. Each significant position in an hexadecimal number has a positional weight. The least significant position has a weight of 16^0, i.e., 1, the higher significant positions are given weights in the ascending powers of 16, i.e., 16^1, 16^2, 16^3, etc., respectively.

Q.5. Explain binary to decimal conversion with the help of example.

Ans. To convert a binary number to its decimal equivalent we use the following expression –

The weight of the nth bit of the number from the right hand side = nth bit × $(\text{Base})^{n-1}$.

First we mark the bit position and then we give the weight of each bit of the number depending on its position. The sum of the weights of all bits gives the equivalent number.

Example – $(11101.110)_2 = (\ )_{10}$

Positional weights –	2^4	2^3	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}
Binary number –	1	1	1	0	1 .	1	1	0

$$(11101.110)_2 = (1 \times 2^4) + (1 \times 2^3) + (1 \times 2^2) + (0 \times 2^1) + (1 \times 2^0) + (1 \times 2^{-1}) + (1 \times 2^{-2}) + (0 \times 2^{-3})$$

$$= 16 + 8 + 4 + 0 + 1 + 0.5 + 0.25 + 0 = \mathbf{(29.75)_{10}} \quad \textbf{Ans.}$$

Q.6. Explain decimal to binary conversion with the help of example.

Ans. There are two methods, which are used to convert a binary number to a decimal number, namely, sum of weights method and double dabble method.

In sum of weights method, the set of binary weight values whose sum is equal to the decimal number is determined.

In the double dabble method, the decimal integer number is converted to binary integer number by successive division of 2 and the decimal fraction is converted to binary fraction by successive multiplication of 2. In this method, the given decimal number is successively divided by 2 till the quotient is zero. The last remainder is the MSB. Thus, the integer numbers read from top to bottom give the equivalent binary fraction. To convert a mixed number to binary, convert the integer and fraction parts individually to binary and then combine them.

Example – Convert the decimal number 15.85 into binary.

Integer Part	**Quotient**	**Remainder**	
15 ÷ 2	7	1	↑
7 ÷ 2	3	1	Read
3 ÷ 2	1	1	
1 ÷ 2	0	1	

15 (Decimal number) = 1111 (Binary number)

Fractional Part –

Fraction	*Fraction × 2*	*Remainder New Fraction*	*Integer*
0.85	1.7	0.7	1 (MSB)
0.7	1.4	0.4	1
0.4	0.8	0.8	0
0.8	1.6	0.6	1
0.6	1.2	0.2	1
0.2	0.4	0.4	0 (LSB)

Thus $(0.85)_{10} = (0.110110)_2$

Therefore, $(15.85)_{10} = (1111.110110)_2$

Q.7. Do the conversions with the help of example –

(i) Binary to octal (ii) Octal to binary.

Ans. (i) Binary to Octal – The binary numbers can be converted into equivalent octal numbers by making groups of 3-bits starting from least significant bit and moving towards most significant bit for integer part of the number. For fractional part, the 3 bit grouping are made from the starting of binary (radix) point.

Example – $(110101.101010)_2 = (\ )_8$

Group of three bits are $\underbrace{110}_{6}\ \underbrace{101}_{5}\ .\ \underbrace{101}_{5}\ \underbrace{010}_{2}$

Convert each group to octal

The result is $\mathbf{(65.52)_8}$ **Ans.**

(ii) ***Octal to Binary*** – To convert an octal number to its equivalent binary number each digit of the given octal number is converted to its 3 bit binary equivalent.

Example – Convert the $(56.34)_8$ to its equivalent binary number.

$$(56.34)_8 = (101)\ (110).(011)\ (100)$$
$$= (101110.011100)_2 = (101110.0111)_2$$

Q.8. Explain the following conversions with the help of example –
(i) Binary to hexadecimal (ii) Hexadecimal to binary.

Ans. (i) Binary to Hexadecimal – Binary number can be converted into the equivalent hexadecimal numbers by making groups of four bits starting from LSB and moving towards MSB for integer part and then replacing each group of four bits by its hexadecimal representation. Consider an example to convert binary number $(1101\ 0010\ 110\ 111\ 0101)_2$ to hexadecimal number.

0011	0100	1011	0111	0101
3	4	B	7	5

$$= (34B75)_{16}$$

(ii) Hexadecimal to Binary – Hexadecimal numbers can be converted into equivalent binary numbers by replacing each next digit by its equivalent 4-bit binary number. This is represented by the example given below –

$(A352.B1)_{16} =$	1010	0011	0101
	A	3	5
	0010	1011	0001
	2	B	1

Thus, $(A352.B1)_{16} = (1010001101010010.10110001)_2$

Q.9. Explain the decimal to octal conversion with the help of example.

Or

How will you convert decimal number in octal ? (R.G.P.V., June 2013)

Ans. To convert the given decimal integer number to octal number, successively divide the given number by factor 8 till the quotient is 0. The last remainder is the MSB. The remainder read from bottom to top give the equivalent octal integer number. To convert the given decimal fractional number

to octal fractional number, successively multiply the decimal fractional number by factor 8 till the product is 0 or till the required accuracy is obtained. The first integer from the top is the MSB. The integer read downward to give the octal fractional number.

Example – Convert $(444.96)_{10}$

Integer Part	**Quotient**	**Remainder**
$444 \div 8$	55	4
$55 \div 8$	6	7
$6 \div 8$	0	6

Reading the remainders from bottom to top, the decimal number $(444)_{10}$ is equivalent to octal $(674)_8$

Fractional Part –

Fraction	*Fraction × 8*	*Remainder New Fraction*	*Integer*
0.96	7.68	0.68	7 (MSB)
0.68	5.44	0.44	5
0.44	3.52	0.52	3
0.52	4.16	0.16	4
0.16	1.28	0.28	1 (LSB)

This process will continue further, so may take the result upto 5 places of octal point

$$(0.96)_{10} = (0.75341)_8$$

Hence the result $(444.96)_{10} = (674.75341)_8$

Q.10. Explain the following conversions with the help of example –

(i) Octal to decimal

(ii) Hexadecimal to decimal.

Ans. (i) Octal to Decimal Conversion – The octal number to decimal number conversion is done by multiply each digit in the octal number with their weight of its position and add all the product terms.

Example – $(4154.24)_8 = (\ )_{10}$

$$(4154.24)_8 = (4 \times 8^3) + (1 \times 8^2) + (5 \times 8^1) + (4 \times 8^0) + (2 \times 8^{-1}) + (4 \times 8^{-2})$$

$$= (2048) + (64) + (40) + (4) + (0.25) + (0.0625)$$

Thus, $(4154.24)_8 = \mathbf{(2156.3125)_{10}}$ **Ans.**

(ii) Hexadecimal to Decimal – The hexadecimal number to decimal number conversion is done by multiply each digit in the hexadecimal number with their weight of its position and add all the product terms.

Example – $(5E2C.7B)_{16} = (\ )_{10}$

$$(5E2C.7B)_{16} = 5 \times 16^3 + 14 \times 16^2 + 2 \times 16^1 + 12 \times 16^0 + 7 \times 16^{-1} + 11 \times 16^{-2}$$
$$= 20480 + 3584 + 32 + 12 + 0.4375 + 0.04297$$
$$= (24108.4805)_{10}$$ **Ans.**

Q.11. Explain the conversion of a decimal number to a hexadecimal with the help of example.

Ans. For the conversion of a decimal number to an equivalent hexadecimal number. the decimal number is divided by 16 successively. For the conversion of decimal fraction to its equivalent hexadecimal fraction the technique of repeated multiplication by 16 is used. The integer part is note down after each multiplication and the new remainder fraction is used for multiplication at the next stage.

Example – Convert $(2586)_{10}$ to its hexadecimal equivalent.

	Quotient	**Remainder**
$2586 \div 16$	161	$10 = A$
$161 \div 16$	10	1
$10 \div 16$	0	$10 = A$

Thus $(2586)_{10} = \mathbf{(A1A)_{16}}$

It may be noted that the remainder of the division processes from the digits of the hexadecimal number and the remainders that are greater than 9 are represented by the letters A through F.

Q.12. Explain the following conversions with the help of example –
(i) Hexadecimal to octal (ii) Octal to hexadecimal.

Ans. (i) Hexadecimal to Octal – To convert a hexadecimal number to octal, the following steps can be applied –

(a) Convert the given hexadecimal number to its binary equivalent.

(b) Form groups of 3 bits, starting from the LSB.

(c) Write the equivalent octal number for each group of 3 bits.

Example – Convert $(47)_{16}$ to its octal equivalent.

$$(47)_{16} = (0100\ 0111)_2 = (01000111)_2 = (107)_8$$

Thus, 47 in hexadecimal is equivalent to 107 in the octal number system.

(ii) Octal to Hexadecimal – To convert an octal number to hexadecimal, the steps are as follows –

(a) Convert the given octal number to its binary equivalent

(b) Form groups of 4 bits, starting from the LSB

(c) Write the equivalent hexadecimal number for each group of 4 bits.

Example – Convert $(46.57)_8$ to its hexadecimal equivalent.

Converting $(46.57)_8$ first to its binary equivalent, we get

$$(46.57)_8 = (100)\,(110).\,(101)\,(111)$$
$$= (100\ 110.\ 101111)_2$$

Now, forming the groups of 4 binary bits to obtain its hexadecimal equivalent we have

$$(100\ 110.101111) = (10)\,(0110).(1011)\,(11)$$
$$= (0010)\,(0110).(1011)\,(1100) = (26.BC)_{16}$$

Q.13. Specify different number systems used in digital electronics. What are floating point numbers ? ***(R.G.P.V., June 2014)***

Ans. **Number Systems** – Refer the ans. of Q.4.

Floating Point Number – A number which has both an integer part as well as a fractional part is called ***real number*** or ***floating-point number.*** A real number may be either positive or negative. Examples of real decimal numbers are 215058, 0.739, – 516.46, – 0.586 etc. Examples of binary real numbers are 101.110, 0.1011, – 101.1011, – 0.1101 etc.

The real number 546.98 can also be written as 5.4698×10^2, 0.009863 as 9.863×10^{-3}, 146.58 as 00.14658×10^3 etc. Such representation is known as scientific form of representation.

In scientific computations, it is often necessary to carry out calculations with very large or very small numbers. Hence, scientists have used a convenient notation in which a number is expressed as a combination of a ***mantissa (or fraction)*** and an ***exponent (or characteristic).*** For example, 350000 may be written as 0.35×10^6, where 0.35 is the mantissa and 6 is the value of the exponent. In the general form a number N may be written as $N = MR^e$, where M is the mantissa, e the exponent and R the radix of the number system.

In a computer, a real or floating-point number is represented by two parts – mantissa and exponent. The first part, the mantissa, is a signed fixed point number. The second part, the exponent indicates the position of the binary or decimal point. For example, the decimal number 3584.69 is represented in floating-point representation as shown below –

Sign		Sign	
0	.358469	0	04
Mantissa		Exponent	

A zero the left most position of the mantissa denotes plus sign. The mantissa may be either a fraction or integer.

Most computers used fractional system of representation for mantissa, but some manufacturers use the integer system. The decimal point shown above is an assumed decimal point. It is not physically indicated in the register.

The exponent shown above + 4 to indicate that the actual position of the decimal point lies four decimal positions to the right of the assumed decimal point. In the above illustration the mantissa has been shown as a fraction.

If we use the integer system of representation for mantissa the number $3584.69 = 358469 \times 10^{-2}$ will be represented as shown below –

Sign	Sign
0 358469	1 02
Mantissa	Exponent

In this representation, sign of the exponent has been shown negative to indicate that the actual position of the decimal point lies two decimal position to the left of the assumed decimal point.

The decimal number $0.0049586 = 0.49586 \times 10^{-2}$ can be represented in the fractional system of representation for mantissa as illustrated below –

Sign	Sign
0 .49586	1 02
Mantissa	Exponent

A negative number –563.5896 can be represented as shown below –

Sign	Sign
1 .5635896	0 03
Mantissa	Exponent

A negative fraction – 0.000258637

$= -0.258637 \times 10^{-3}$ can be represented as

Sign	Sign
1 .258637	1 03
Mantissa	Exponent

The floating-point binary number is also represented in the same manner. For example, the binary number 1011.1010 can be represented in a 16 bit register as shown below –

Sign	Sign
0 .10111010	0 000100
Mantissa	Exponent

The mantissa occupies 9 bits and the exponents 7 bits. The binary point is not physically indicated in the register, but it is only assumed to be there.

In general form a floating-point number is expressed as

$$N = M \times R^{e}$$

The mantissa M and the exponent e are physically present in a register of a computer. But the Radix R and the radix point are not indicated in the register.

Q.14. What do you mean by signed and unsigned number ?

Ans. In the decimal system, we put + or – sign before a number to represent its sign. In computer such notation cannot be employed and

therefore, a different technique has been adopted. To represent positive sign a 0 is placed before the binary number. For example +9 is represented by 01001. To represent negative number a 1 is placed before the number. For example, – 9 will be represented as 11001. There is only one way to represent a positive number. But there are three different ways to represent a negative number. These are –

(i) Signed – Magnitude representation

(ii) Signed – 1's complement representation

(iii) Signed – 2's complement representation.

The representation of –9 in above three representations are shown below –

Signed – Magnitude representation	11001
Signed – 1's complement representation	10110
Signed – 2's complement representation	10111.

Hence, 9 is represented by 4 binary bits and a separate bit is used to represent sign. In a computer, the MSB can be used to represent the sign of the number. For example, an 8 bit computer will represent –9 as shown below. 7 bits are used to represent the number and the MSB is used to represent the sign of the number.

Signed – Magnitude representation	10001001
Signed – 1's complement representation	11110110
Signed – 2's complement representation	11110111

When all the bits of the computer word are used to represent the number and no bit is used for sign representation it will be called unsigned representation of the number.

Q.15. What do you mean by 1's complement representation ? Explain with example.

Ans. The 1's complement in the binary number system is similar to 9's complement in the decimal system. To obtain 1's complement of a binary number each bit of the binary number is subtracted from 1. Thus 1's complement of a binary number may be formed by simply changing each 1 to a 0 and each 0 to a 1.

Example – The 1's complement of the binary number 010 is 101.

Q.16. Write short note on 2's complement. ***(R.G.P.V., May 2019)***

Ans. The 2's complement in the binary number system is similar to 10's complement in the decimal number system. The 2's complement of a binary number is equal to the 1's complement of the number plus one.

The 2's complement of a binary number = Its 1's complement + 1.

Example – The 2's complement of 0101 = 1010 + 1 = 1011.

NUMERICAL PROBLEMS

Prob.1. Convert the following indicating the steps involved.

(i) $(657)_8 = (?)_{16}$ *(ii)* $(1D53)_{16} = (?)_{10}$ *(iii)* $(131.F2)_{16} = (?)_{10}$

(R.G.P.V., June 2014)

Sol. (i) Converting $(657)_8$ first to its binary equivalent

$$(657)_8 = (110\ \ 101\ \ 111)$$

Now, forming the groups of 4 binary bits to obtain its hexadecimal equivalent, we get

$$= \begin{array}{ccc} \underbrace{0001} & \underbrace{1010} & \underbrace{1111} \\ \downarrow & \downarrow & \downarrow \\ 1 & 10 & 15 \\ \downarrow & \downarrow & \downarrow \\ 1 & A & F \end{array}$$

$(657)_8 = \mathbf{(1AF)}$ **Ans.**

(ii) $(1D53)_{16} = 1 \times 16^3 + 13 \times 16^2 + 5 \times 16^1 + 3 \times 16^0$

$= \mathbf{(7507)_{10}}$ **Ans.**

(iii) $(131.F2)_{16} = 1 \times 16^2 + 3 \times 16^1 + 1 \times 16^0 + 15 \times 16^{-1} + 2 \times 16^{-2}$

$= \mathbf{(305.94)_{10}}$ **Ans.**

Prob.2. Obtain the following –

(i) Binary equivalent of $(12372)_8$

(ii) Octal equivalent of $(10010110.1011)_2$

(iii) Hexadecimal equivalent of $(2391)_{10}$

(iv) Decimal equivalent to $(11011000)_2$.

(R.G.P.V., June 2012)

Sol. (i) $(12372)_8 = (\ \ )_2 = (001010011111010)_2$

$(12372)_8 = \mathbf{(001010011111010)_2}$ **Ans.**

(ii) $(10010110.1011)_2 = (\ \ )_8$

$$\begin{array}{cccccc} (\underbrace{010} & \underbrace{010} & \underbrace{110} & . & \underbrace{101} & \underbrace{100}) \\ \downarrow & \downarrow & \downarrow & & \downarrow & \downarrow \\ 2 & 2 & 6 & & 5 & 4 \end{array}$$

$(10010110.1011)_2 = \mathbf{(226.54)_8}$ **Ans.**

(iii) $(2391)_{10} = (\quad)_{16}$

$$\begin{array}{r|l} 16 & 2391 \\ \hline 16 & \ \ 149 \rightarrow 7 \\ \hline & \ \ \ \ 9 \rightarrow 5 \end{array} \uparrow$$

$(2391)_{10} = (957)_{16}$ **Ans.**

(iv) $(11011000)_2 = (\quad)_{10}$

$$= 1 \times 2^7 + 1 \times 2^6 + 0 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$$

$$= 128 + 64 + 16 + 8 = 216$$

$(11011000)_2 = \mathbf{(216)_{10}}$ **Ans.**

Prob.3. Convert the following numbers into decimal –

(i) $(11111111)_2$ (ii) $(100)_8$ (iii) $(FFFF)_{16}$

(iv) $(01010101)_2$ (v) $(100.100)_2$

(R.G.P.V., Dec. 2011)

Sol. (i) $(11111111)_2 = 1 \times 2^7 + 1 \times 2^6 + 1 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$

$= \mathbf{(255)_{10}}$ **Ans.**

(ii) $(100)_8 = 1 \times 8^2 + 0 \times 8^1 + 0 \times 8^0 = \mathbf{(64)_{10}}$ **Ans.**

(iii) $(FFFF)_{16} = F \times 16^3 + F \times 16^2 + F \times 16^1 + F \times 16^0$

$= 15 \times 16^3 + 15 \times 16^2 + 15 \times 16^1 + 15 \times 16^0$

$= \mathbf{(65535)_{10}}$ **Ans.**

(iv) $(01010101)_2 = 0 \times 2^7 + 1 \times 2^6 + 0 \times 2^5 + 1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$

$= \mathbf{(85)_{10}}$ **Ans.**

(v) $(100.100)_2 = 1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0 + 1 \times 2^{-1} + 0 \times 2^{-2} + 0 \times 2^{-3}$

$= 4 + 1/2 = \mathbf{(4.5)_{10}}$ **Ans.**

Prob.4. Convert as directed –

(i) $(39)_{10}$ decimal to $(?)_2$ binary

(ii) $(1213)_8$ octal to $(?)_{10}$ decimal

(iii) $(16E)_{16}$ Hexadecimal to $(?)_2$ binary

(iv) $(10101011)_2$ binary to $(?)_8$ octal.

(R.G.P.V., May 2018)

Sol. (i) $(39)_{10} = (\quad)_2$

Successive Division		Remainder
2	39	1 (LSB)
2	19	1
2	9	1
2	4	0
2	2	0
2	1	1 (MSB)

i.e., $(39)_{10} = \mathbf{(100111)_2}$ **Ans.**

(ii) $(1213)_8 = (\quad)_{10}$

$$(1213)_8 = 1 \times 8^3 + 2 \times 8^2 + 1 \times 8^1 + 3 \times 8^0$$
$$= 512 + 128 + 8 + 3$$
$$= \mathbf{(651)_{10}}$$ **Ans.**

(iii) $(16E)_{16} = (\quad)_2$

$$= \underset{0001}{\underset{\downarrow}{1}} \quad \underset{0110}{\underset{\downarrow}{6}} \quad \underset{1110}{\underset{\downarrow}{E}}$$

$$= (000101101110)_2 = \mathbf{(101101110)_2}$$ **Ans.**

(iv) $(10101011)_2 = (\quad)_8$

$$(10101011)_2 = \underset{2}{\underset{\downarrow}{\underline{010}}} \quad \underset{5}{\underset{\downarrow}{\underline{101}}} \quad \underset{3}{\underset{\downarrow}{\underline{011}}}$$

$$= \mathbf{(253)_8}$$ **Ans.**

Prob.5. Convert the following numbers into decimal –

(i) $(1001010.0101)_2$ (ii) $(12212)_3$ (iii) $(8.3)_9$.

Also find the 2's complement of –

(i) $(110110)_2$ (ii) $(10000)_2$.

(R.G.P.V., Dec. 2012)

Sol. (i) $(1001010.0101)_2 = (\quad)_{10}$

$$= 1 \times 2^6 + 0 \times 2^5 + 0 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1$$
$$+ 0 \times 2^0 + 0 \times 2^{-1} + 1 \times 2^{-2} + 0 \times 2^{-3} + 1 \times 2^{-4}$$
$$= 64 + 8 + 2 + \frac{1}{4} + \frac{1}{16}$$
$$= 74 + 0.25 + 0.0625$$
$$= (74.3125)_{10}$$

$$(1001010.0101)_2 = \mathbf{(74.3125)_{10}}$$ **Ans.**

(ii) $(12212)_3 = (\quad)_{10}$

$$= 1 \times 3^4 + 2 \times 3^3 + 2 \times 3^2 + 1 \times 3^1 + 2 \times 3^0$$
$$= 81 + 54 + 18 + 3 + 2$$
$$= 158$$

$$(12212)_3 = \mathbf{(158)_{10}}$$ **Ans.**

(iii) $(8.3)_9 = (\quad)_{10}$

$$= 8 \times 9^0 + 3 \times 9^{-1}$$
$$= 8 + \frac{3}{9}$$

$$(8.3)_9 = \mathbf{(8.3333)_{10}}$$ **Ans.**

2's complement of

(i) $(110110)_2$

Number	110110
1's comp.	001001
1 add	1
	001010

$(110110)_2$ of 2's complement is **(001010)**. **Ans.**

(ii) $(10000)_2$

Number	10000
1's comp.	01111
1 add	1
	10000

(10000) of 2's complement is **(10000)**. **Ans.**

Prob.6. Using 2's complement substract $(100111)_2$ from $(110011)_2$. ***(R.G.P.V., Dec. 2010)***

Sol. We have find

$$(110011)_2 - (100111)_2$$

2's complement of 100111

= 1's complement of 100111 + 1

= 011000

+1

= 011001

then

110011

011001

1,001100

↑

Discarded carry

= **001100** **Ans.**

DEMORGAN'S THEOREM, LOGIC GATES

Q.17. What do you mean by Boolean algebra ?

Ans. Boolean algebra is a system of mathematical logic. The Boolean algebra is governed by certain well-developed rules and laws. Any single variable, or a function of the variables can have a value of either 0 or 1.

Boolean algebra differs from both the ordinary algebra and the binary number system. In Boolean algebra, $A + A = A$ and $A.A = A$, because the variable A has only a logical value. In ordinary algebra, $A + A = 2A$ and $A.A = A^2$, because the

variable A has numerical value here. In Boolean algebra, $1 + 1 = 1$, whereas in the binary number system, $1 + 1 = 10$, and in ordinary algebra, $1 + 1 = 2$.

Q.18. Explain the postulates and laws of Boolean algebra.

Ans. **Boolean Postulates** – Fundamental conditions or self-evident propositions are called postulates. The postulates for Boolean algebra originate from the three basic logic operations – AND, OR and NOT. The properties of these basic operations as given in tables 5.7, 5.6 and 5.8 are the postulates for Boolean algebra. These are called ***Boolean postulates*** and they are summarized in table 5.1. These postulates define the operation of the AND, OR and NOT. In other words these are the results of these basic operations.

Table 5.1 Boolean Postulates

(i)	$0.0 = 0$	Derived from AND operation
(ii)	$0.1 = 0$	
(iii)	$1.0 = 0$	
(iv)	$1.1 = 1$	
(i)	$0 + 0 = 0$	Derived from OR operation
(ii)	$0 + 1 = 1$	
(iii)	$1 + 0 = 1$	
(iv)	$1 + 1 = 1$	
(i)	$\bar{0} = 1$	Derived from NOT operation
(ii)	$\bar{1} = 0$	

(i) Properties of AND Operation –

(a) $0.X = 0$

(b) $X.0 = 0$

(c) $1.X = X$

(d) $X.1 = X$

(a) $\mathbf{0.X = 0}$

Proof. If $X = 0, 0.X = 0.0$ [by postulate (i)]

$= 0$

If $X = 1, 0.X = 0.1$

$= 0$ [by postulate (ii)]

Therefore, $0.X = 0$ **Proved**

(b) Similarly (a)

(c) $\mathbf{1.X = X}$

Proof. If $X = 0, 1.X = 1.0 = 0$ [by postulate (iii)]

$= X$

If $X = 1, 1.X = 1.1 = 1$ [by postulate (iv)]

$= X$

Therefore, $1.X = X$ **Proved**

(d) Similarly (c)

(ii) Properties of OR Operation –

(a) $X + 0 = X$

(b) $0 + X = X$

(c) $X + 1 = 1$

(d) $1 + X = 1$

(a) $X + 0 = X$

Proof. If $X = 0$ then $X + 0 = 0 + 0 = 0 = X$

If $X = 1$, $X + 0 = 1 + 0 = 1 = X$ [by postulate (i)]

Therefore, $X + 0 = X$ [by postulate (iii)]

Proved

(b) Similarly (a)

(c) $X + 1 = 1$

Proof. If $X = 0$, $X + 1 = 0 + 1 = 1$ [by postulate (ii)]

If $X = 1$, $X + 1 = 1 + 1 = 1$ [by postulate (iv)]

Therefore, $X + 1 = 1$

Proved

(d) Similarly (c)

(iii) Commutative Law –

(a) $X + Y = Y + X$

(b) $X.\ Y = Y.X$

(a) $X + Y = Y + X$

Proof. If $Y = 0$, $X + Y = X + 0$

$= X$ [by properties (ii) (a)]

$Y + X = 0 + X$

$= X$ [by properties (ii) (b)]

Therefore, $X + Y = Y + X$

If $Y = 1$, $X + Y = X + 1$

$= 1$ [by properties (ii) (c)]

$Y + X = 1 + X$

$= 1$ [by properties (ii) (d)]

Therefore, $X + Y = Y + X$

Proved

(b) Similarly (a)

(iv) Associative Law –

(a) $X.(Y.Z) = (X.Y).\ Z = X.Y.Z$

(b) $X + (Y + Z) = (X + Y) + Z$

The associative property of addition is given by

$$X + (Y + Z) = (X + Y) + Z$$

The OR operation of several variables result in the same, regardless of the grouping of the variables.

The associative law of multiplication is given by

$$X.(Y.\ Z) = (X.Y).Z$$

According to this law, it makes no difference in what order the variables are grouped during the AND operation of several variables.

(v) Distributive Law –

(a) $X + Y.Z = (X + Y).(X + Z)$

(b) $X.(Y + Z) = X.Y + X.Z$

(a) $\mathbf{X + (Y.Z) = (X + Y).(X + Z)}$

Proof.

$$
\begin{aligned}
X + (Y.Z) &= X.1 + Y.Z && [\because X1 = X] \\
&= X.(1 + Y) + Y.Z && [\because 1 + Y = 1] \\
&= X.1 + X.Y + Y.Z \\
&= X(1 + Z) + X.Y + Y.Z && [\because 1 + Z = 1] \\
&= X.1 + X.Z + X.Y + Y.Z \\
&= X.X + X.Z + X.Y + Y.Z && [\because X.X = X] \\
&= X.(X + Z) + Y.(X + Z) \\
&= (X + Y).(X + Z) && \textbf{Proved}
\end{aligned}
$$

(b) Similarly (a).

(vi) Absorption Law –

(a) $X + X.Y = X$

(b) $X.(X + Y) = X$

(c) $X.Y + X.\overline{Y} = X$

(d) $(X + Y)(X + \overline{Y}) = X$

(a) $\mathbf{X + X.Y = X}$

Proof.

$$
\begin{aligned}
X + X.Y &= X.(1 + Y) \\
&= X.1 && [\because 1 + Y = 1] \\
&= X && \textbf{Proved}
\end{aligned}
$$

(b) $\mathbf{X.(X + Y) = X}$

Proof.

$$
\begin{aligned}
X.(X + Y) &= X.X + X.Y \\
&= X + X.Y && [\because X.X = X] \\
&= X.(1 + Y) \\
&= X.1 && [\because 1 + Y = 1] \\
&= X && [\because X.1 = X] \\
& && \textbf{Proved}
\end{aligned}
$$

(c) $\mathbf{X.Y + X.\overline{Y} = X}$

Proof.

$$
\begin{aligned}
X.Y + X.\overline{Y} &= X.(Y + \overline{Y}) \\
&= X.1 && [\because Y + \overline{Y} = 1] \\
&= X && [\because X.1 = X]
\end{aligned}
$$

(d) $\mathbf{(X + Y).(X + \overline{Y}) = X}$

Proof.

$$
\begin{aligned}
(X + Y).(X + \overline{Y}) &= X.X + X.\overline{Y} + Y.X + Y.\overline{Y} \\
&= X + X.\overline{Y} + X.Y + 0 && [\because Y.\overline{Y} = 0] \\
&= X + X.(\overline{Y} + Y) \\
&= X + X.(Y + \overline{Y}) \\
&= X + X.1 && [\because Y + \overline{Y} = 1] \\
&= X + X && [\because X.1 = X] \\
&= X && [\because X + X = X] \quad \textbf{Proved}
\end{aligned}
$$

Q.19. Verify that the following operations are commutative and associative –
(i) AND (ii) OR (iii) EX-OR
(R.G.P.V., June 2013)

Ans. Refer the ans. of Q.18.

Q.20. State and prove De-Morgan's theorem and illustrate them using an example for each. ***(R.G.P.V., April 2009)***

Or

State and explain De-Morgan's theorem.
(R.G.P.V., June 2013, Dec. 2008, 2013, 2014)

Or

State De-Morgan's theorem with example. ***(R.G.P.V., June 2014)***

Or

State and prove De-Morgan's theorem using two variables.
(R.G.P.V., June 2009, Sept. 2009, June 2012)

Or

Write short note on De-Morgan's theorem. ***(R.G.P.V., May 2019)***

Ans. **First Theorem** – It states that complement of two or more variables when they are ORed together is same as those of complements of each input when they are ANDed together. In other words, a NOR gate is equivalent to a bubbles AND gate. For two input variables A and B

$$\overline{(A+B)} = \overline{A}.\overline{B}$$

The table 5.2 shows the truth table which shows the validity of this theorem –

Table 5.2

A	B	$\overline{A}$	$\overline{B}$	$\overline{A+B}$	$\overline{A}.\overline{B}$
0	0	1	1	1	1
0	1	1	0	0	0
1	0	0	1	0	0
1	1	0	0	0	0

Fig. 5.1 shows the logic diagram for two input variables of the theorem.

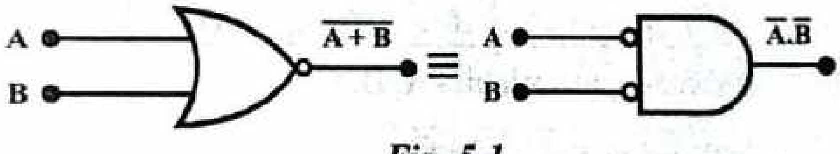


Fig. 5.1

The columns 5 and 6 of the truth table are identical. Hence we say that the two circuits are logically equivalent. Give the same inputs, the outputs are the same.

Similarly, for three input variables A, B, C

$$\overline{A+B+C} = \overline{A}.\overline{B}.\overline{C}$$

Fig. 5.2 shows the logic diagram for three input variables of the theorem.

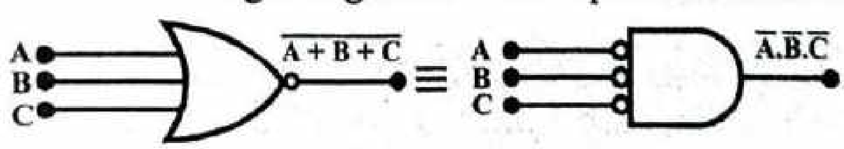


Fig. 5.2

The following truth table shows the validity of theorem for three input variables.

Table 5.3

A	B	C	$\overline{A}$	$\overline{B}$	$\overline{C}$	$\overline{A+B+C}$	$\overline{A}.\overline{B}.\overline{C}$
0	0	0	1	1	1	1	1
0	0	1	1	1	0	0	0
0	1	0	1	0	1	0	0
0	1	1	1	0	0	0	0
1	0	0	0	1	1	0	0
1	0	1	0	1	0	0	0
1	1	0	0	0	1	0	0
1	1	1	0	0	0	0	0

Second Theorem – It states that complement of two or more variables when they are ANDed together is same as those of complement of each input when they are ORed together. In other words, a NAND gate is equivalent to a bubbled OR gate. For two input variables A, B –

$$\overline{A.B} = \overline{A} + \overline{B}$$

Fig. 5.3 shows the logic diagram for the two input variables of the theorem.

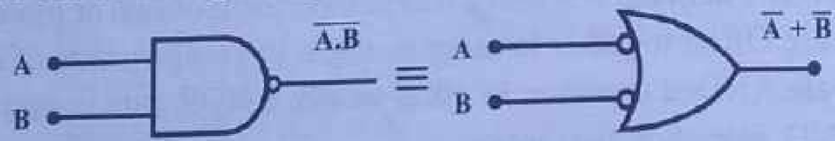


Fig 5.3

The following truth table shows the validity of this theorem –

Table 5.4

A	B	$\overline{A}$	$\overline{B}$	$\overline{A.B}$	$\overline{A}+\overline{B}$
0	0	1	1	1	1
0	1	1	0	1	1
1	0	0	1	1	1
1	1	0	0	0	0

Similarly, for three-input variables A, B, C

$$\overline{(A.B.C)} = \overline{A} + \overline{B} + \overline{C}.$$

Fig. 5.4 shows the logic diagram for the three input variables of the theorem.

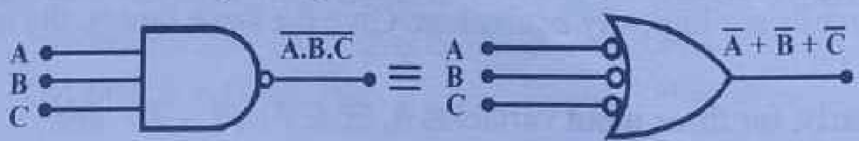


Fig. 5.4

The following truth table shows the validity of theorem for three input variables –

The columns 7 and 8 of the truth table are identical. Hence we say that the two circuits are logically equivalent. Given the same inputs, the outputs are the same.

Table 5.5

A	B	C	$\overline{A}$	$\overline{B}$	$\overline{C}$	$\overline{A.B.C}$	$\overline{A}+\overline{B}+\overline{C}$
0	0	0	1	1	1	1	1
0	0	1	1	1	0	1	1
0	1	0	1	0	1	1	1
0	1	1	1	0	0	1	1
1	0	0	0	1	1	1	1
1	0	1	0	1	0	1	1
1	1	0	0	0	1	1	1
1	1	1	0	0	0	0	0

Q.21. Define truth table.

Ans. The table that lists all the possible combinations of input variables and the corresponding outputs is known as truth table.

It represents how the logic circuit's output responds to various combinations of logic levels at the inputs.

Q.22. What is level logic ?

Ans. The level logic is defined as a logic in which the voltage levels represent logic-1 and logic-0. Level logic may be positive logic or negative logic.

A positive logic system is one in which the higher of the two voltage levels represents the logic-1 and the lower of the two voltage levels represents the logic-0. A negative logic system is one in which the lower of the two voltage levels represents the logic-1 and the higher of the two voltage levels represents the logic-0.

Q.23. What are logic gates ? Enlist the different types of logic gates ?
(R.G.P.V., June 2013)

Or

Write short note on logic gates. ***(R.G.P.V., May 2018)***

Ans. **Logic Gates –** The logic gates are electronic circuits because they are made up of a number of electronic devices and components. The logic circuits that perform the logical operations of AND, OR and NOT are called gates.

The inputs and outputs of logic gates can occur only in two levels, such as HIGH (or 1) and LOW (or 0).

The graphic symbols and truth tables of the eight gates are shown in fig. 5.5. Each gate has one or two binary input variables designated by x and y and are binary output variable designated by F.

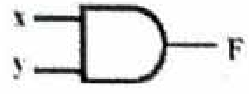
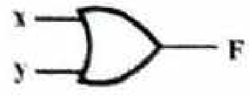
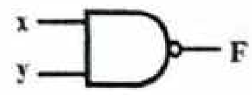
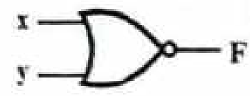
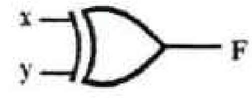
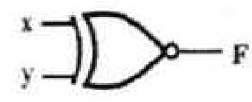
Name	Graphic Symbol	Algebraic Function	Truth Table
AND		F = xy	x y | F 0 0 | 0 0 1 | 0 1 0 | 0 1 1 | 1
OR		F = x + y	x y | F 0 0 | 0 0 1 | 1 1 0 | 1 1 1 | 1
Inverter		F = x'	x | F 0 | 1 1 | 0
Buffer		F = x	x | F 0 | 0 1 | 1
NAND		F = (xy)'	x y | F 0 0 | 1 0 1 | 1 1 0 | 1 1 1 | 0
NOR		F = (x + y)'	x y | F 0 0 | 1 0 1 | 0 1 0 | 0 1 1 | 0
Exclusive-OR (XOR)		F = xy' + x'y $= x \oplus y$	x y | F 0 0 | 0 0 1 | 1 1 0 | 1 1 1 | 0
Exclusive-NOR or equivalence		F = xy + x'y' $= (x \oplus y)'$	x y | F 0 0 | 1 0 1 | 0 1 0 | 0 1 1 | 1

Fig. 5.5

Q.24. Explain the operation of OR gate. Draw the logic symbol and write the truth table for OR gate.

Ans. The OR gate performs logical addition, commonly known as OR function. The OR gate has two or more inputs and only one output. The operation of OR gate is such that a HIGH (1) on the output is produced when any of the inputs is HIGH(1). The output is LOW (0) only when all the inputs are LOW(0).

If A and B are the input variables of an OR gate and Y is its output, then

$$Y = A + B$$

Similarly, for more than two variables, the OR function can be expressed as

$$Y = A + B + C + D \ldots$$

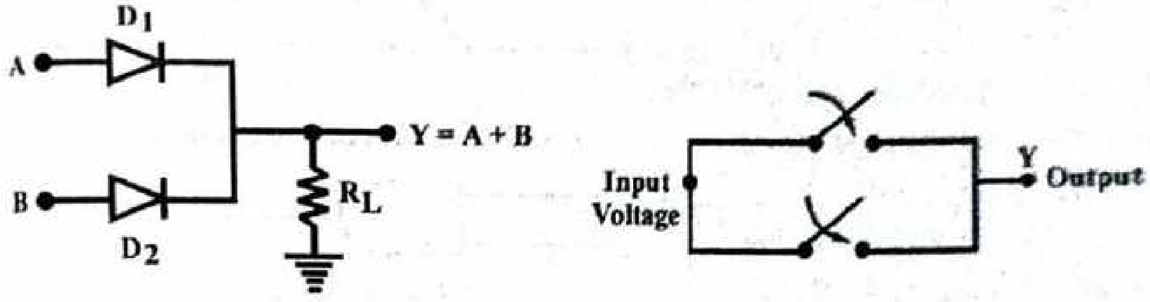
An OR gate using diodes is shown in fig. 5.6 (a) in which A and B represent the inputs and Y the output. The resistance R_L is the load resistance.

If A = 0 and B = 0 both the diodes will not conduct and hence the output Y = 0.

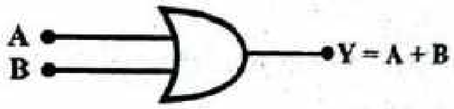
If A = 1 and B = 0, diode D_1 conducts, then $V_0 \approx 5V$ and so Y = 1

If A = 0 and B = 1, diode D_2 conducts and hence Y = 1

If A = 1 and B = 1, both the diodes conduct and hence Y = 1.



(a) Circuit Diagram using Diodes *(b) Its Electrical Equivalent*



(c) Logical Symbol

Fig. 5.6 2-input OR Gate

The electrical equivalent circuit of an OR gate is shown in fig. 5.6 (b) where switches A and B are connected in parallel. If either A or B is closed or if both are closed, then the output is high. The logic symbol for a 2-input OR gate is shown in fig. 5.6 (c). The logical operation of the two input OR gate is described in the truth table shown in table 5.6.

Table 5.6

Inputs		*Output*
A	*B*	*Y = A + B*
0	0	0
0	1	1
1	0	1
1	1	1

Q.25. Explain the operation of AND gate. Give the truth table and logic symbol for AND gate.

Ans. The AND gate performs logical multiplication, commonly known as AND function. The AND gate has two or more inputs and a single output. The output of an AND gate is HIGH only when all the inputs are HIGH. Even if any one of the inputs is LOW, the output will be LOW.

If A and B are the input variables of an AND gate and Y is its output, then

$$Y = A.B$$

where the dot (.) denotes the AND operation. Moreover, one typically deletes the dot and writes as Y = AB.

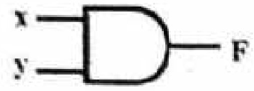
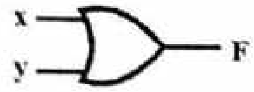
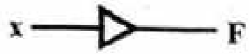
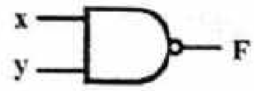
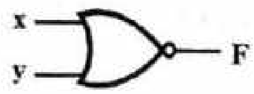
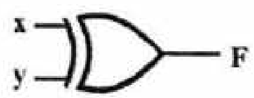
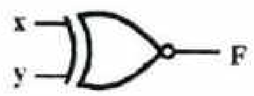
Name	*Graphic Symbol*	*Algebraic Function*	*Truth Table*
AND		F = xy	x y | F 0 0 | 0 0 1 | 0 1 0 | 0 1 1 | 1
OR		F = x + y	x y | F 0 0 | 0 0 1 | 1 1 0 | 1 1 1 | 1
Inverter		F = x'	x | F 0 | 1 1 | 0
Buffer		F = x	x | F 0 | 0 1 | 1
NAND		F = (xy)'	x y | F 0 0 | 1 0 1 | 1 1 0 | 1 1 1 | 0
NOR		F = (x + y)'	x y | F 0 0 | 1 0 1 | 0 1 0 | 0 1 1 | 0
Exclusive-OR (XOR)		F = xy' + x'y = x ⊕ y	x y | F 0 0 | 0 0 1 | 1 1 0 | 1 1 1 | 0
Exclusive-NOR or equivalence		F = xy + x'y' = (x ⊕ y)'	x y | F 0 0 | 1 0 1 | 0 1 0 | 0 1 1 | 1

Fig. 5.5

Q.24. Explain the operation of OR gate. Draw the logic symbol and write the truth table for OR gate.

Ans. The OR gate performs logical addition, commonly known as OR function. The OR gate has two or more inputs and only one output. The operation of OR gate is such that a HIGH (1) on the output is produced when any of the inputs is HIGH(1). The output is LOW (0) only when all the inputs are LOW(0).

If A and B are the input variables of an OR gate and Y is its output, then

$$Y = A + B$$

Similarly, for more than two variables, the OR function can be expressed as

$$Y = A + B + C + D \ldots$$

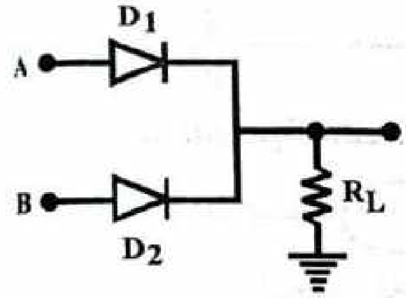
An OR gate using diodes is shown in fig. 5.6 (a) in which A and B represent the inputs and Y the output. The resistance R_L is the load resistance.

If A = 0 and B = 0 both the diodes will not conduct and hence the output Y = 0.

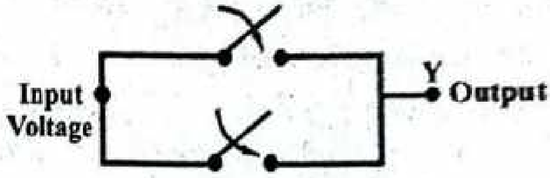
If A = 1 and B = 0, diode D_1 conducts, then $V_0 \approx 5V$ and so Y = 1

If A = 0 and B = 1, diode D_2 conducts and hence Y = 1

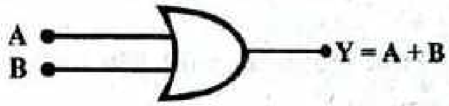
If A = 1 and B = 1, both the diodes conduct and hence Y = 1.



(a) Circuit Diagram using Diodes



(b) Its Electrical Equivalent



(c) Logical Symbol

Fig. 5.6 2-input OR Gate

The electrical equivalent circuit of an OR gate is shown in fig. 5.6 (b) where switches A and B are connected in parallel. If either A or B is closed or if both are closed, then the output is high. The logic symbol for a 2-input OR gate is shown in fig. 5.6 (c). The logical operation of the two input OR gate is described in the truth table shown in table 5.6.

Table 5.6

Inputs		*Output*
A	*B*	*Y = A + B*
0	0	0
0	1	1
1	0	1
1	1	1

Q.25. Explain the operation of AND gate. Give the truth table and logic symbol for AND gate.

Ans. The AND gate performs logical multiplication, commonly known as AND function. The AND gate has two or more inputs and a single output. The output of an AND gate is HIGH only when all the inputs are HIGH. Even if any one of the inputs is LOW, the output will be LOW.

If A and B are the input variables of an AND gate and Y is its output, then

$$Y = A.B$$

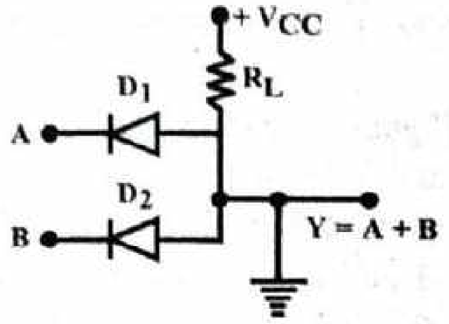
where the dot (.) denotes the AND operation. Moreover, one typically deletes the dot and writes as Y = AB.

A 2-inputs AND gate using diodes is shown fig. 5.7 (a) in which A and B represent the inputs and Y the output.

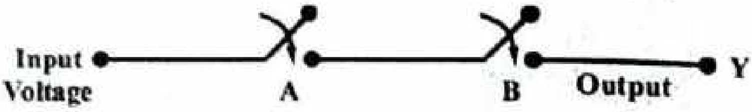
If A = 0 and B = 0, both the diodes conduct as they are forward biased, and hence the output is Y = 0.

If A = 0 and B = 1, the diode D_1 conducts and D_2 does not conduct, and hence the output is Y = 0.

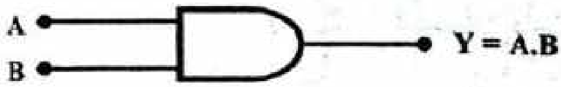
If A = 1 and B = 0, the diode D_1 does not conduct and D_2 conducts, and hence the output is Y = 0.



(a) Circuit Diagram using Diodes



(b) Its Electrical Equivalent



(c) Logic Symbol

Fig. 5.7 2-input AND Gate

If A = 1 and B = 1, both the diodes do not conducts as they are reverse biased, and hence the output is Y = 1.

The electrical equivalent circuit of an AND gate is shown in fig. 5.7 (b), where two switches A and B are connected in series. If both A and B are closed, then the output is high. Logic symbol of the 2 inputs AND gate is shown in fig. 5.7 (c). The logical operation of the two inputs AND gate and the three input AND gate are described in the truth table shown in table 5.7.

Table 5.7

Inputs		*Output*
A	*B*	*Y = A.B*
0	0	0
0	1	0
1	0	0
1	1	1

Q.26. Explain the operation of NOT gate. Draw the logic symbol and write the truth table for NOT gate.

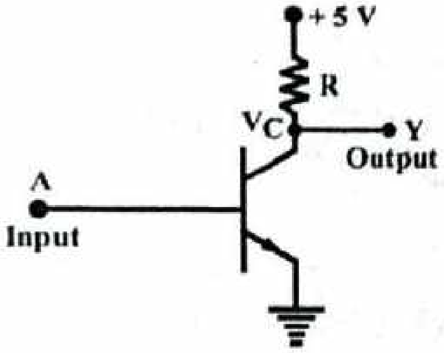
Ans. The NOT gate performs the basic logical function called ***inversion*** or ***complementation.*** The purpose of this gate is to convert one logic level into the opposite logic level. It has one input and one output. When a HIGH level is applied to an inverter, a LOW level appears at its output and vice versa.

Table 5.8

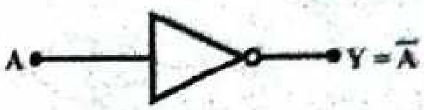
Input	*Output*
A	$Y = \overline{A}$
0	1
1	0

A NOT gate using a transistor is shown in fig. 5.8 (a), in which A represents the input and Y represent the output i.e., $Y = \overline{A}$. When the input is HIGH, the transistor is in the ON state and the output $V_C = V_{CE(set)}$ is LOW. If the input is LOW, the transistor is in the OFF state and the output $V_C = V_{CC}$ is HIGH.

The symbol for the inverter is shown in fig. 5.8 (b), the truth table of a NOT gate is given in table 5.8.



(a) Circuit Diagram using Transistor



(b) Logical Symbol

Fig. 5.8

Q.27. What are universal gates ? Implement all basic gates using universal gates. ***(R.G.P.V., Dec. 2008)***

Ans. NAND and NOR gates are called ***universal gates*** or universal building blocks because both can be used to implement any gate like AND, OR and NOT gates or any combination of these basic gates. Fig. 5.9 shows how a NAND gate can be used to realise various logic gates while fig. 5.10 shows how a NOR gate can be used for the same.

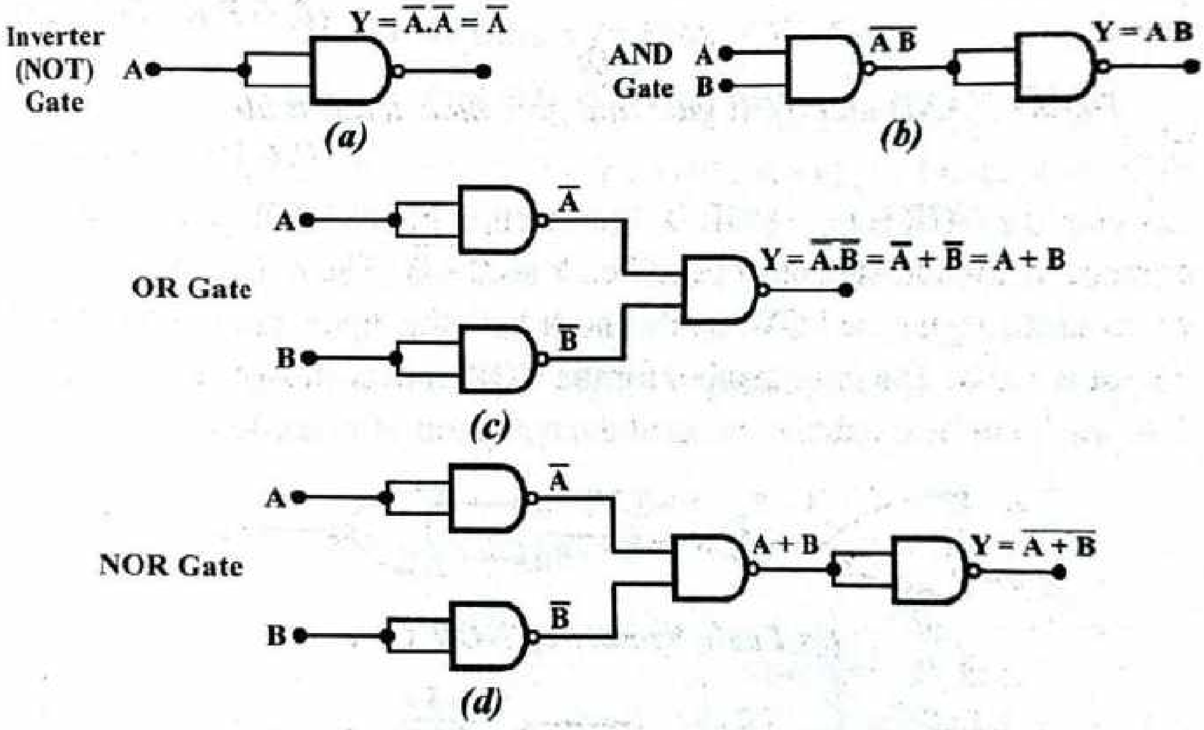
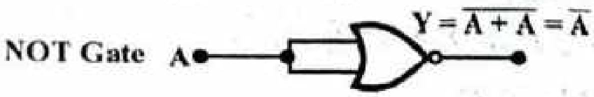


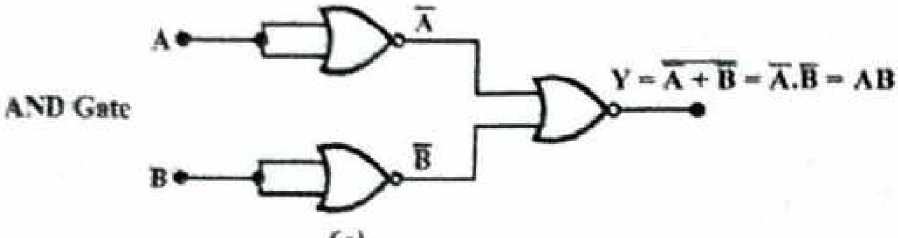
Fig. 5.9 Realisation of

(a) NOT (b) AND (c) OR and (d) NOR gates using NAND gates

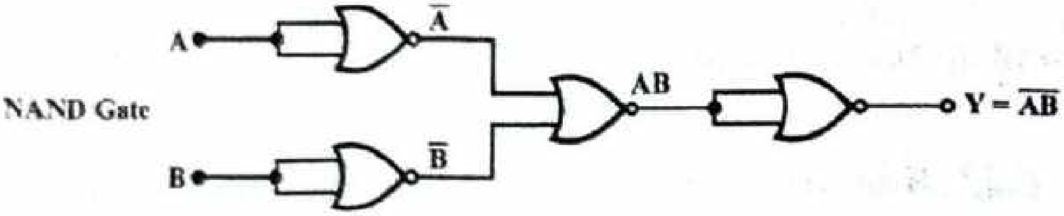


(a)

(b)



(c)



(d)

Fig. 5.10 Realisation of

(a) NOT (b) OR (c) AND and (d) NAND gates using NOR gates

Q.28. Write symbols and truth table for the following –
(i) NAND gate (ii) NOR gate.

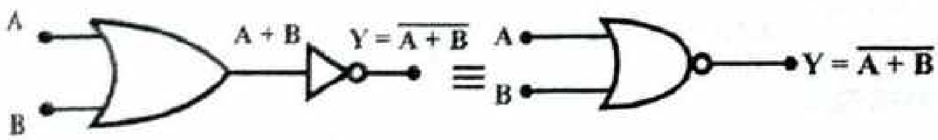
(R.G.P.V., Feb. 2010)

Or

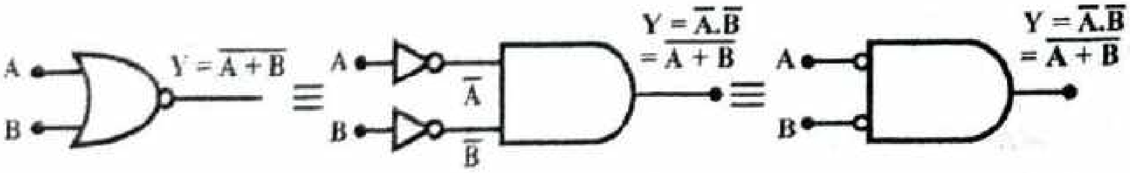
Define NAND and NOR gate and give their truth tables.

(R.G.P.V., Dec. 2010)

Ans. (i) NOR Gate – NOR is a contraction of NOT-OR gates. It has two or more inputs and only one output i.e., $Y = \overline{A + B}$. The output is HIGH only when all the inputs are LOW. If any one or both the inputs are HIGH, then the output is LOW. The logic symbol for the NOR gate is shown in fig. 5.11 (a). The small circle or bubble represent the operation of inversion.



(a) Logic Symbol of NOR Gate



(b) NOR Gate ≡ Bubbled AND Gate

Fig. 5.11

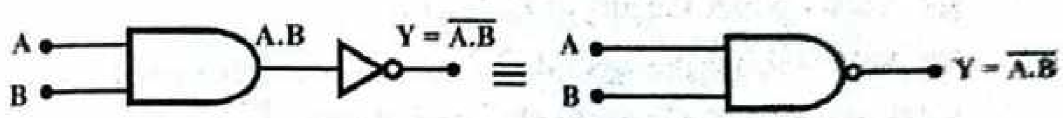
The truth table of a two input NOR gate is shown in table 5.9.

The NOR gate is equivalent to an AND gate with a bubble at its inputs. This is shown in fig. 5.11 (a) and (b).

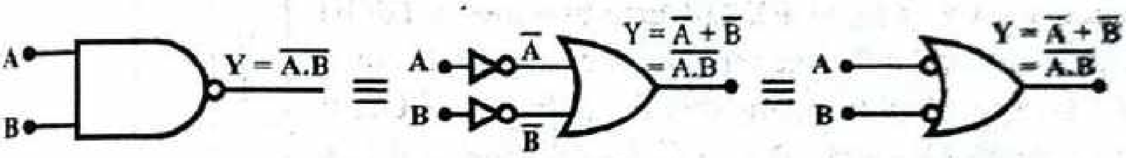
Table 5.9

Inputs			*Output*
A	*B*	*A + B*	$Y = \overline{A+B}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

(ii) NAND Gate – NAND gate is a universal gate like NOR because they can perform the function of basis gates OR, AND and NOT. In fact, any logic circuit can be designed with NAND gate. Since in NAND ≡ NOT + AND in fig. 5.12.



(a) Logic Symbol of NAND Gate



(b) NAND Gate ≡ Bubbled AND Gate

Fig. 5.12 NAND Gate

The electrical circuit in fig. 5.13 shows of not a glow of lamp if switches A and B are closed the entire current of cell. Fig. 5.13 gives the electronic circuitry of diodes-transistor. If diodes the entire current D_1 and D_2 conduct. If A = 1, B = 1 or one of them conduct the point N become grounded or (0) transistor Q is not conducting as base N grounded. This cutting off of transistor Q will enhance the potential of $Y = V_{CC}$ i.e., logically meaning $A - B = \overline{A.B} = 0$.

The truth table is shown in table 5.10.

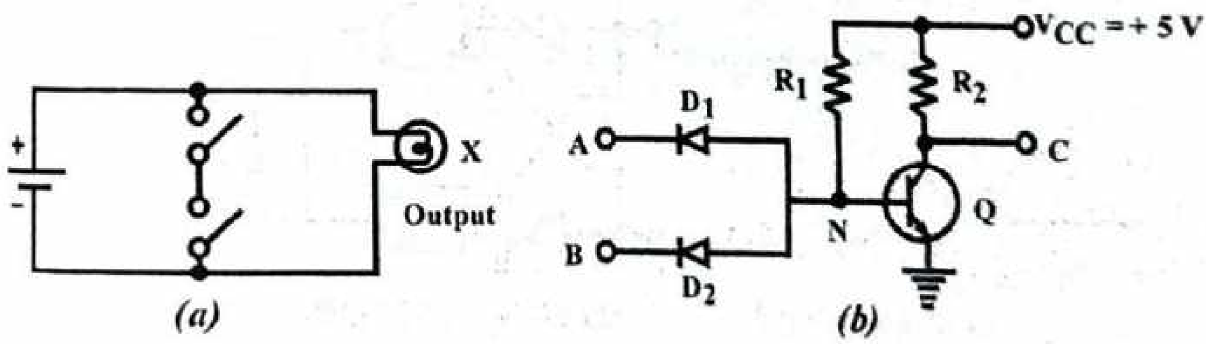


Fig. 5.13

Table 5.10

Inputs			*Output*
A	*B*	*A.B*	$Y = \overline{A.B}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

Q.29. Give the logic symbol and truth table for the following logic gates –
(i) NAND (ii) NOR (iii) NOT (iv) EX-OR.

(R.G.P.V., Dec. 2011)

Ans. *(i)* ***NAND*** – Refer the ans. of Q.28 (ii).

(ii) ***NOR*** – Refer the ans of Q.28 (i).

(iii) ***NOT*** – Refer the ans. of Q.26.

(iv) ***Exclusive-OR Gate*** – Exclusive-OR gate is gate with two or more inputs and one output. The output of a two input EX-OR gate assumes a HIGH state if one and only one input assumes a HIGH state. This is equivalent to saying that the output is HIGH if either input A or input B is HIGH exclusive, and low when both are 1 or 0 simultaneously.

Table 5.11

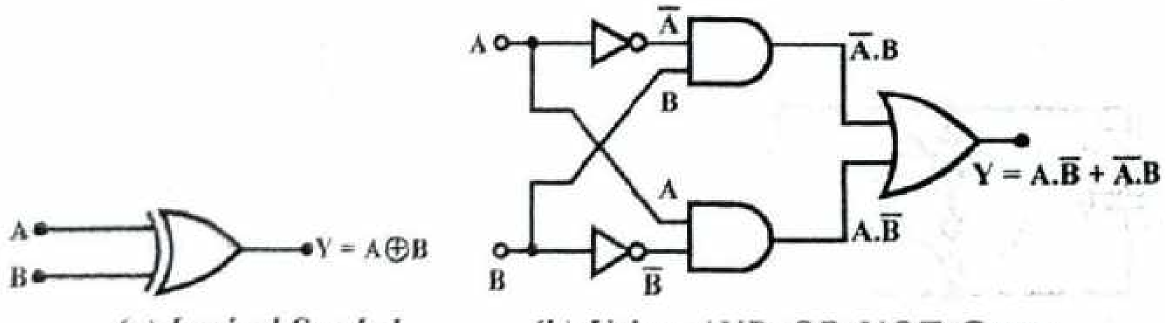
Inputs		*Output*
A	*B*	$Y = A \oplus B$
0	0	0
0	1	1
1	0	1
1	1	0

The truth table of the EX-OR gate shows that the output is HIGH when any one but not all, of the inputs is at 1. This exclusive feature eliminates a similarity to the OR gate. The EX-OR gate responds with a HIGH output only when an odd number of inputs is HIGH. When there is an even number of HIGH inputs such as two or four, the output will always be LOW. From the truth table of a 2-input EX-OR gate, the EX-OR function can be written as

$$Y = A \oplus B$$

$$Y = \overline{A}B + A\overline{B}$$

The XOR operation is called modulo 2-sum operation. Fig. 5.14 shows the standard symbol for a 2-inputs XOR gate. Table 5.11 shows its truth table.



(a) Logical Symbol *(b) Using AND-OR-NOT Gates*

Fig. 5.14

Q.30. Write and explain truth table of –
(i) NAND gate (ii) EX-OR gate. (R.G.P.V., Dec. 2013)

Ans. (i) NAND Gate – Refer the ans. of Q.28 (ii).

(ii) EX-OR Gate – Refer the ans. of Q.29 (iv).

Q.31. What is an EX-NOR gate ? Write its truth table. (R.G.P.V., June 2013)

Ans. The exclusive-NOR gate, abbreviated EX-NOR, is an EX-OR gate followed by an inverter. An exclusive-NOR gate has two or more inputs and one output. The output of a two-input EX-NOR gate assumes a HIGH state if both the inputs assume the same logic state or have an even number of 1's, and its output is LOW when the inputs assume different logic states or have an odd number of 1s. The logic symbol of EX-NOR gate is shown in fig. 5.15 and its truth table is given in table 5.12. From the truth table it is clear that the EX-NOR output is the complement of the EX-OR gate. The Boolean expression for the EX-NOR gate is

Table 5.12

Inputs		***Output***
A	***B***	$Y = \overline{A \oplus B}$
0	0	1
0	1	0
1	0	0
1	1	1

$$Y = \overline{A \oplus B}$$

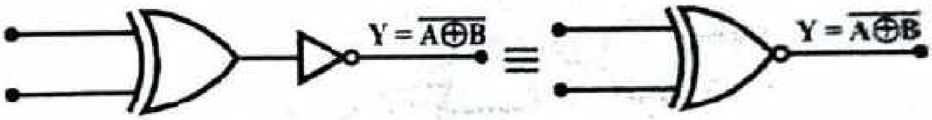


Fig. 5.15

According to De-Morgan's theorem

$$\overline{A \oplus B} = \overline{\overline{A}B + A\overline{B}} = \overline{\overline{A}B}.\overline{A\overline{B}} = (A + \overline{B}).(\overline{A} + B)$$

or
$$\overline{A \oplus B} = AB + \overline{A}.\overline{B}$$

NUMERICAL PROBLEMS

Prob.7. State and prove De-Morgan's theorems for two variables. Simplify –

$$f = (A + \overline{B}C) + \overline{(A + \overline{B}.C)} \qquad \textit{(R.G.P.V., June 2011)}$$

Sol. **De-Morgan's Theorem** – Refer to the ans. of Q.20.

$$F = (A + \overline{B}.C) + \overline{(A + \overline{B}.C)}$$
$$= (A + \overline{B}C) + (\overline{A}.\overline{\overline{B}.C})$$
$$= (A + \overline{B}C) + [\overline{A}.(B + \overline{C})]$$
$$= A + \overline{B}C + \overline{A}B + \overline{A}\,\overline{C}$$
$$= A(B + \overline{B})(C + \overline{C}) + \overline{B}C(A + \overline{A}) + \overline{A}B(C + \overline{C}) + \overline{A}\,\overline{C}(B + \overline{B})$$

$$= (AB+A\overline{B})(C+\overline{C})+A\overline{B}C+\overline{A}\,\overline{B}C+\overline{A}BC+\overline{A}B\overline{C}+\overline{A}B\overline{C}+\overline{A}\,\overline{B}\,\overline{C}$$

$$= ABC+AB\overline{C}+A\overline{B}C+A\overline{B}\overline{C}+A\overline{B}C+\overline{A}\,\overline{B}C$$

$$+\overline{A}BC+\overline{A}B\overline{C}+\overline{A}B\overline{C}+\overline{A}\,\overline{B}\,\overline{C}$$

$$= ABC+AB\overline{C}+A\overline{B}C+A\overline{B}\,\overline{C}+\overline{A}\,\overline{B}C+\overline{A}BC+\overline{A}B\overline{C}+\overline{A}\,\overline{B}\,\overline{C}$$

$$= AB(C+\overline{C})+A\overline{B}(C+\overline{C})+\overline{A}C(\overline{B}+B)+\overline{A}\,\overline{C}(B+\overline{B})$$

$$= AB+A\overline{B}+\overline{A}C+\overline{A}\,\overline{C}$$

$$= A(B+\overline{B})+\overline{A}(C+\overline{C}) = A+\overline{A} = 1 \qquad \textbf{Ans.}$$

Prob.8. Simplify the Boolean function $Z = AB + \overline{A}C + BC$ and therefore design the logic circuit using AND or OR logic gates. (R.G.P.V., Dec. 2014)

Sol.

$$\begin{aligned} Z &= AB+\overline{A}C+BC \\ &= AB(C+\overline{C})+\overline{A}(B+\overline{B})C+(A+\overline{A})BC \\ &= ABC+AB\overline{C}+\overline{A}BC+\overline{A}\,\overline{B}C+ABC+\overline{A}BC \\ &= ABC+AB\overline{C}+\overline{A}BC+\overline{A}\,\overline{B}C \\ &= AB(C+\overline{C})+\overline{A}C(B+\overline{B}) \quad (\because C+\overline{C}, B+\overline{B}=1) \\ &= AB+\overline{A}C \end{aligned}$$

The logic circuit is shown in fig. 5.16.

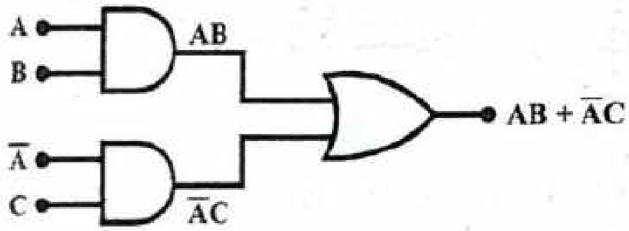


Fig. 5.16 $Z = AB + \overline{A}C$

Prob.9. Design EX-OR and EX-NOR gate using NOR gate and NAND gate. (R.G.P.V., March/April 2010)

Sol. (i) Realization of EX-OR Gate using NOR Gate and NAND Gate – The EX-OR gate is shown in fig. 5.17.

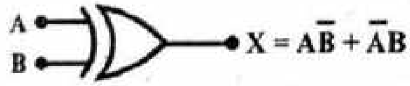


Fig. 5.17

(a) Using NAND Gate –

$$\begin{aligned} X &= A\overline{B}+\overline{A}B \\ &= A\overline{A}+A\overline{B}+\overline{A}B+B\overline{B} \\ &= A(\overline{A}+\overline{B})+B(\overline{A}+\overline{B}) \;] \\ &= A\overline{AB}+B\overline{AB} \\ &= \overline{\overline{A\overline{AB}+B\overline{AB}}} = \overline{\overline{A\overline{AB}}\;\overline{B\overline{AB}}} \end{aligned}$$

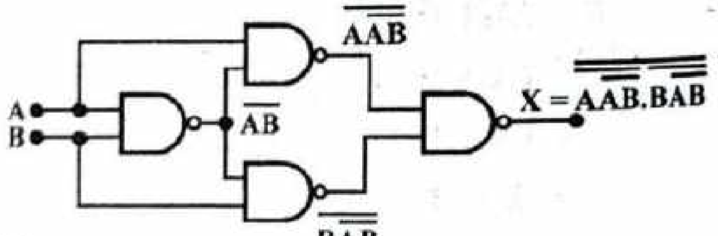


Fig. 5.18

(b) Using NOR Gate –

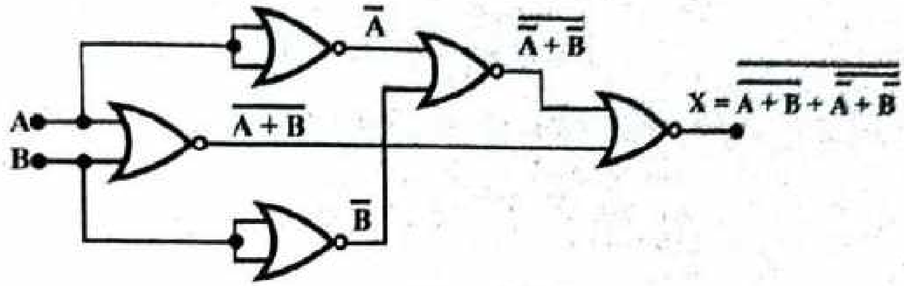


Fig. 5.19

$$
\begin{aligned}
X &= A\overline{B} + \overline{A}B \\
&= A\overline{A} + A\overline{B} + \overline{A}B + B\overline{B} \\
&= A(\overline{A} + \overline{B}) + B(\overline{A} + \overline{B}) = (A + B)(\overline{A} + \overline{B}) \\
&= \overline{\overline{(A + B)(\overline{A} + \overline{B})}} = \overline{\overline{(A + B)} + \overline{(\overline{A} + \overline{B})}}
\end{aligned}
$$

(ii) Realization of EX-NOR Gate using NOR Gate and NAND Gate – The EX-NOR gate is shown in fig. 5.20.

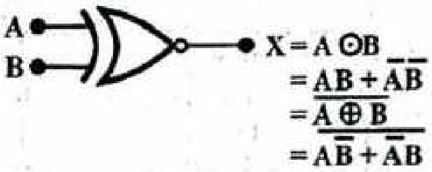


Fig. 5.20

(a) Using NAND Gate

$$
\begin{aligned}
X &= AB + \overline{A}\,\overline{B} \\
&= A\overline{A} + AB + \overline{A}\,\overline{B} + B\overline{B} \\
&= A(\overline{A} + B) + \overline{B}(\overline{A} + B) \\
&= \overline{\overline{A(\overline{A\overline{B}}) + \overline{B}(\overline{A\overline{B}})}} \\
&= \overline{\overline{A(\overline{A\overline{B}})}.\overline{\overline{B}(\overline{A\overline{B}})}}
\end{aligned}
$$

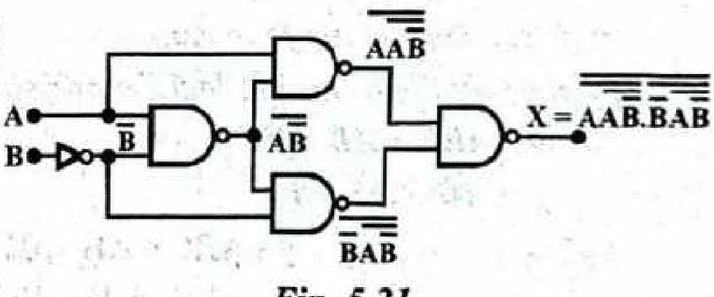


Fig. 5.21

(b) Using NOR Gate –

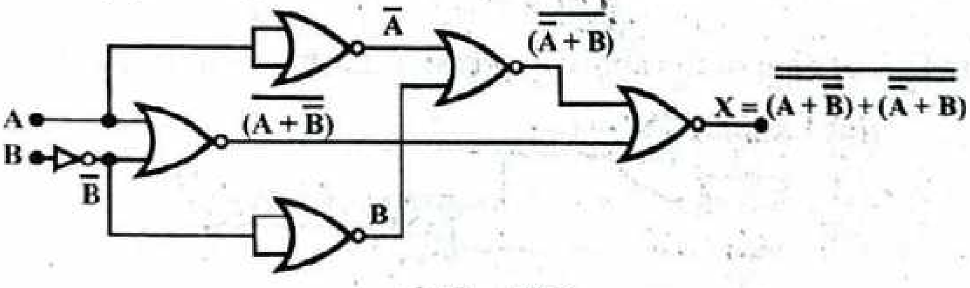


Fig. 5.22

$$
\begin{aligned}
X &= AB + \overline{A}\,\overline{B} \\
&= A\overline{A} + AB + \overline{A}\,\overline{B} + B\overline{B}
\end{aligned}
$$

$$= A(\overline{A} + B) + \overline{B}(\overline{A} + B)$$

$$= \overline{\overline{(A + \overline{B})(\overline{A} + B)}} = \overline{\overline{(A + \overline{B})} + \overline{(\overline{A} + B)}}$$

Prob.10. Draw the truth table of the following logic circuit

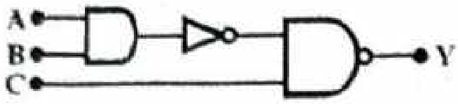


Fig. 5.23

(R.G.P.V., June 2012)

Sol. First, given logic circuit, we simplify –

$$Y_{out} = \overline{\overline{AB}.C}$$

$$= \overline{\overline{AB}} + \overline{C} = AB + \overline{C}$$

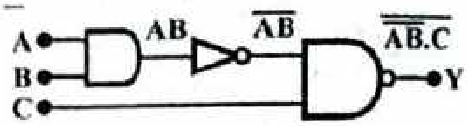


Fig. 5.24

According to given equation, we can drive the truth table –

Truth Table

A	B	C	$Y_{out} = AB + \overline{C}$
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

Prob.11. Answer the following –

Implement the following logic expressions with logic gates –

$y = ABC + AB + BC$

$y = ABC(D + EF)$. ***(R.G.P.V., June 2013)***

Sol.

$$y = ABC + AB + BC$$

$$y = AB(C + 1) + BC \qquad (\because 1 + C = 1)$$

$$y = AB + BC$$

$$= B(A + C)$$

Implementation of the above expression is shown in fig. 5.25.

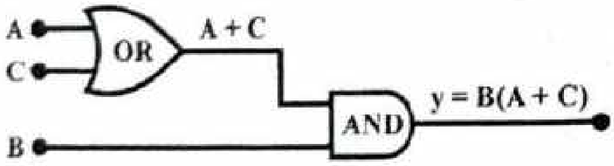


Fig. 5.25

and $$y = ABC(D + EF)$$

Implementation of the above expression is shown in fig. 5.26.

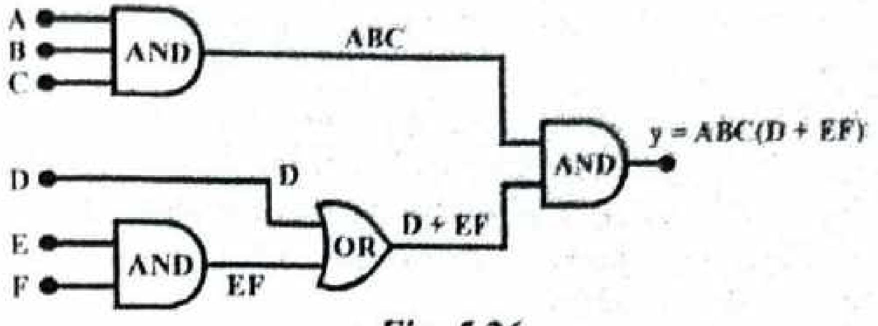


Fig. 5.26

HALF AND FULL ADDER CIRCUITS, R-S FLIP FLOP, J-K FLIP FLOP

Q.32. What is the need of arithmetic and logic circuits ?

Ans. Digital computers consists of arithmetic and logic circuits, which contain logic gates and flip-flops that add, subtract, multiply and divide binary numbers. The basic building blocks of the arithmetic unit in a digital computer are adders. A digital system consists of two types of circuits –

(i) Combinational logic circuit (ii) Sequencial logic circuit.

Q.33. Distinguish between combinational and sequential logic circuits giving example of each. ***(R.G.P.V., Dec. 2011)***

Ans. The differences between a combinational circuit and a sequential circuit are as follows –

S.No.	*Combinational Circuit*	*Sequential Circuit*
(i)	It contains no memory elements.	It contains memory elements.
(ii)	The present values of its outputs are determined solely by the present values of its inputs.	The present values of its outputs are determined by the present values of its inputs and its present state.
(iii)	Its behaviour is described by the set of output functions. **Example** – Half adder, Full adder	Its behaviour is described by the set of next-state functions and the set of output functions. **Example** – flip flop

Q.34. Explain the operation of half adder and full adder along with their logic diagram and truth table. ***(R.G.P.V., June 2014)***

Or

Explain half adder and full adder with truth table. (R.G.P.V., Dec. 2014)

Or

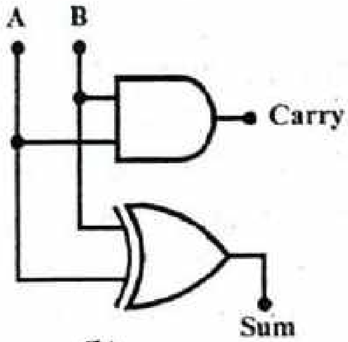
Explain the half adder and full adder. ***[R.G.P.V., Nov. 2018(O)]***

Ans. **Half Adder** – A half adder is a combinational circuit that can be used for adding two bits. It has two input variables and two outputs i.e., sum and carry.

The output sum is high when the inputs are different i.e., one is low and another is high and the output carry is high when the inputs are high. Otherwise, the sum and carry will be low. The logic symbol and truth table of half adder is shown below. The truth table shows the working of half adder. Fig. 5.27 shows the logic circuit of the half adder.

$$\text{SUM} = A \oplus B = \overline{A}.B + A.\overline{B} \quad ...(i)$$

$$\text{CARRY} = A.B \quad ...(ii)$$



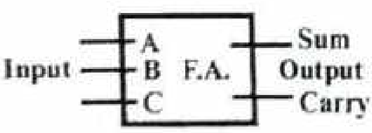
(a) (b)

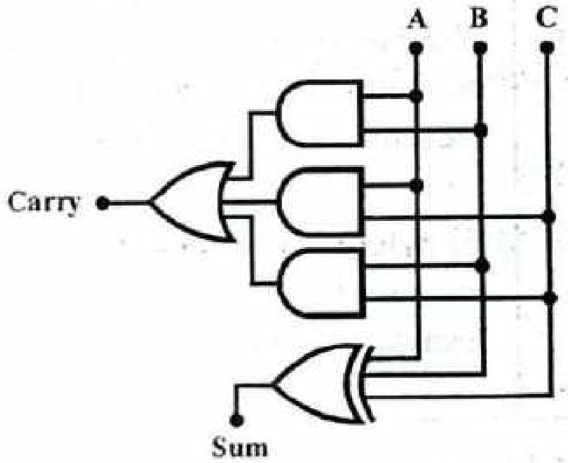
Fig. 5.27 Half Adder

Table 5.13

Inputs		*Outputs*	
A	*B*	*Sum*	*Carry*
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Full Adder – A full adder is a combinational circuit that can be used for adding three bits. It has three input variables and two outputs i.e., sum and carry. The output sum is high when the high input variables are odd in number otherwise, the sum is low. Similarly, carry is high when two or more input variables are high otherwise, carry will be low. The logic symbol and truth table of full adder is shown below. The truth table shows the working of full adder.





(a) (b)

Fig. 5.28 Full Adder

Fig. 5.28 shows the logic circuit of the full adder.

$$\text{SUM} = A \oplus B \oplus C = \overline{A}.\overline{B}.C + \overline{A}.B.\overline{C} + A.\overline{B}.\overline{C} + A.B.C \quad ...(iii)$$

$$\text{CARRY} = A.B + B.C + A.C \quad ....(iv)$$

The sum term of the full adder is the X-OR of A, B and C i.e., the sum bit is the modulo sum of the data bits in that column and the carry from the previous column. The logic diagram of the full adder using two X-OR gates and two AND gates (i.e., two half adders) and one OR gate as shown in fig. 5.29.

Table 5.14

Inputs			*Outputs*	
A	*B*	*C*	*Sum*	*Carry*
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

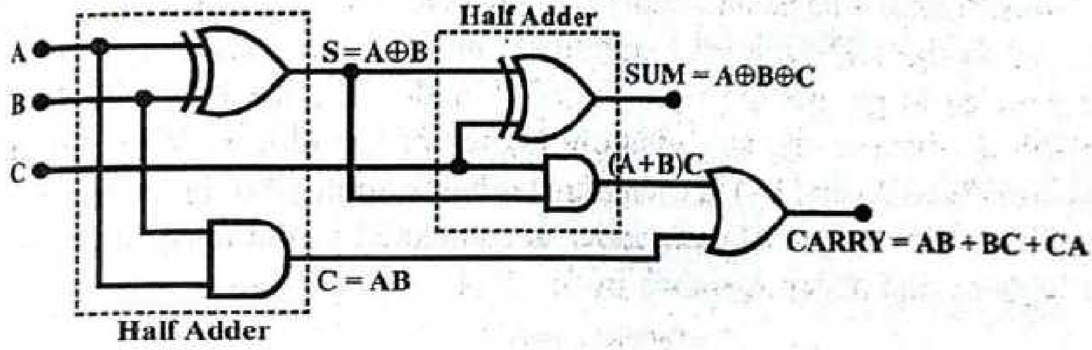


Fig. 5.29 Logic Diagram of a Full Adder using Two Half Adders

Q.35. State De-Morgan's theorem. Specify the truth table and logic diagram for full adder circuit. ***(R.G.P.V., Dec. 2012)***

Ans. **De-Morgan's Theorem** – Refer the ans. of Q.20.

Full Adder – Refer the ans. of Q.34.

Q.36. Draw the circuit diagram of a half adder and derive its truth table. ***(R.G.P.V., Feb. 2010, June 2010, Dec. 2011)***

Or

What is a half adder ? How is it realised using logic gates ? ***(R.G.P.V., Dec. 2010)***

Ans. Refer the ans. of Q.34.

Q.37. Design a full adder circuit using NAND gates. ***(R.G.P.V., June 2013)***

Ans. Let $A \oplus B = \overline{\overline{A.\overline{AB}}.\overline{B.\overline{AB}}} = X$. Then

$$S = A \oplus B \oplus C_{in}$$

$$= \overline{\overline{X.\overline{XC_{in}}}.\overline{C_{in}.\overline{XC_{in}}}} = X \oplus C_{in}$$

$$C_{out} = C_{in}(A \oplus B) + AB$$

$$= \overline{\overline{C_{in}(A \oplus B)}.\overline{AB}}$$

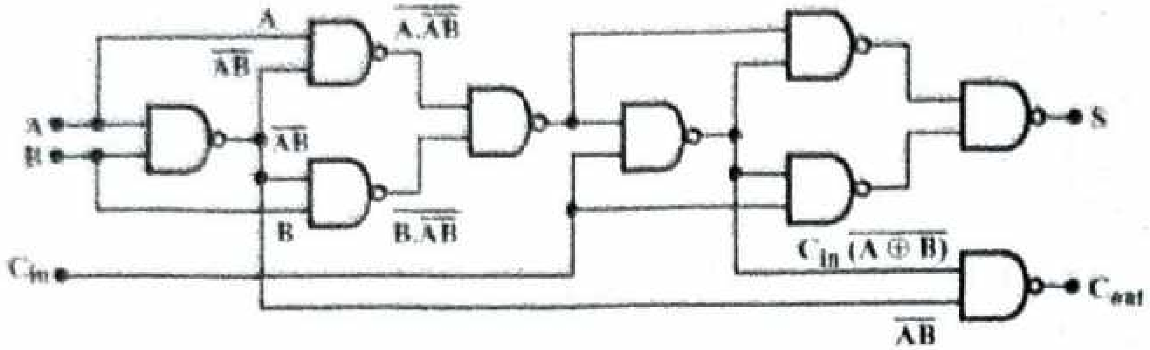


Fig. 5.30 Logic Diagram of a Full-adder Using Only 2-Input NAND Gates

Q.38. Draw and explain 4-bit full adder circuit. (R.G.P.V., Dec. 2013)

Ans. A basic 4-bit parallel adder is implemented with four full-adder stages as given in fig. 5.31. The least significant bits (A_0 and B_0) in each number being added to go into the right most full-adder, the higher order bits are applied as given to the successively higher order adders. With the most significant bits (A_3 and B_3) in each number being applied to the left most full-adder. The carry output of each adder is connected to the carry input of the next higher order adder as shown in fig. 5.31.

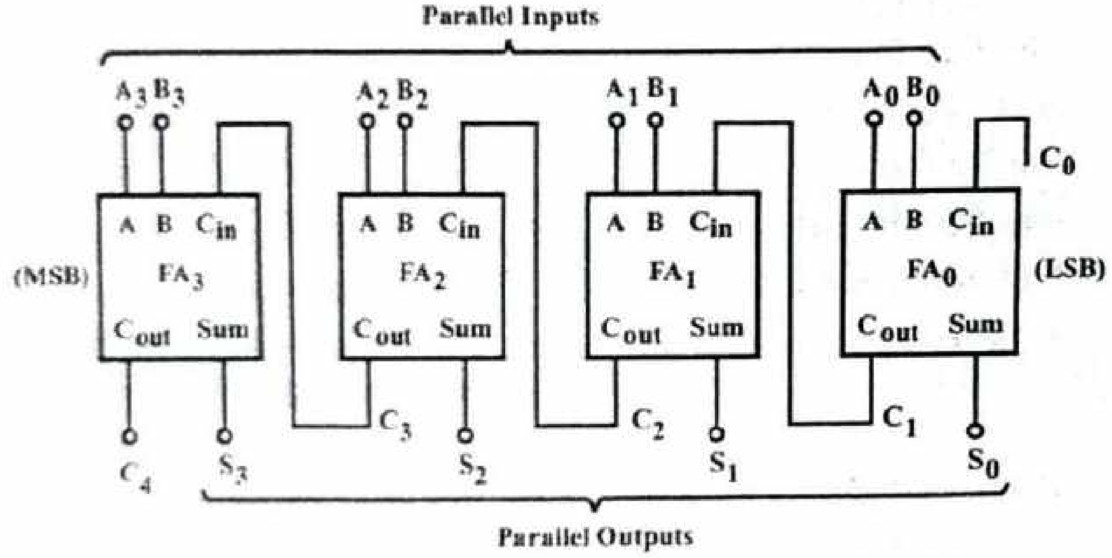


Fig. 5.31 Block Diagram of a 4-bit Binary Parallel Adder

There are two types of parallel adder in terms of the method used to handle carries, namely ripple carry adder and the look-ahead carry adder. The carry output of each full-adder is connected to the carry input of the next higher order stage, then the adder is known as ripple carry adder. The method of speeding up the addition process by eliminating this ripple carry delay is known as look-ahead carry addition. The look-ahead carry adder anticipates the output carry of each stage and based on the input bits of each stage, produces the output carry by either carry generation or carry propagation.

The carry generation occurs when an output carry is generated internally by the full-adder. A carry is generated only when both input bits are 1's. The carry generated C_g is expressed as the AND function of the two input bits A

and B as -

$$C_g = AB$$

The carry propagation (C_p) occurs when the input carry is ripped to become the output carry. An input carry may be propagated by the full-adder when either or both of the input bits are 1's. The propagated carry (C_p) is expressed as the OR function of the input bits.

$$C_p = A \oplus B$$

The truth table of a 4-bit binary parallel adder is given in table 5.15. The subscript n represents the adder bits and can be 0, 1, 2 and for the 4-bit parallel adder. C_{n-1} is the carry from the previous adder.

Table 5.15 Truth Table of a 4-bit Parallel Adder

Row Number	C_{n-1}	A_n	B_n	S_n	C_n	
0	0	0	0	0	0	No carry generation, i.e., $C_{out} = 0$
1	0	0	1	1	0	
2	0	1	0	1	0	Carry propagation, i.e., $C_{out} = C_{in}$
3	0	1	1	0	1	
4	1	0	0	1	0	
5	1	0	1	0	1	
6	1	1	0	0	1	Carry generation, i.e., $C_{out} = 1$
7	1	1	1	1	1	

Q.39. What is flip-flop ?

Ans. The simplest kind of sequential circuit is a memory cell that has only two states. It can be either 1 or 0. Such two state sequential circuit is called ***flip-flop*** because they flip from one state to another and then flop back. A flip-flop is also known as ***bistable multivibrator, latch*** or ***toggle***.

The general block diagram representation of a flip-flop is shown in fig. 5.32. The two outputs are complementary to each other, if Q = 0 i.e., Reset, then $\overline{Q} = 1$; if Q = 1 i.e., Set, then $\overline{Q} = 0$.

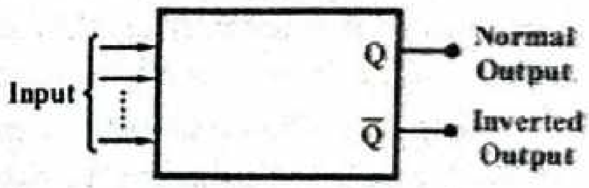


Fig. 5.32 Block Diagram of a Flip-flop

Q.40. What is R-S flip-flop ? Give its limitations. (R.G.P.V., Dec. 2008)

Ans. The S-R flip-flop has two inputs, namely Set (S) and Reset (R), and two outputs Q and $\overline{Q}$. The two outputs are complement to each other. The S-R flip-flop can be easily implemented using NOR gates or NAND gates. The block diagram of S-R flip-flop is shown in fig. 5.33.

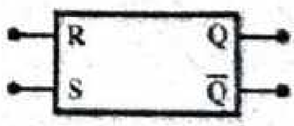


Fig. 5.33 Block Diagram

Limitations – The SR flip-flop is limited to one mode of operation, asynchronous. But in most practical sequential circuit design, it is often desirable to have some form of clock input to the flip-flop so that the device may be operated simultaneously (synchronously) with all others in the system. It is this requirement that led to the development of the other types of flip-flops.

Q.41. Explain the NOR-based S-R flip flop with the help of circuit diagram and truth table.

Ans. The S-R flip-flop can be easily constructed using two NOR gates connected back-to-back, as shown in fig. 5.34. The cross-coupled connections from the output of one gate to the input of the other gate constitute a feedback path. For this reason, the circuits are classified as asynchronous sequential circuits. The truth table for the NOR-based S-R flip-flop is shown in table 5.16.

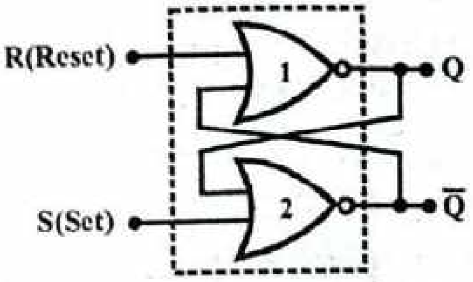


Fig. 5.34 NOR-based S-R Flip-flop

To analyse the circuit of fig. 5.33, one must remember that the output of a NOR gate is 0 if any input is 1 and the output is 1 only when all inputs are 0. From the truth table, it is evident that four possible input combinations exist for the S-R flip-flop. The outputs for these four possible input combinations are described below.

Case 1 – For S = 0 and R = 0, the flip-flop simply remains in its present state (Q_n). That is the next state of the flip-flop (Q_{n+1}) is just the present state. In this situation, the next state of the flip-flop will be $Q_{n+1} = 0$ if $Q_n = 0$ and $Q_{n+1} = 1$ if $Q_n = 1$. First, let us assume that $Q_n = 0$ and $\overline{Q}_n = 1$. The inputs of NOR gate-1 are 1 and 0, and therefore its output $Q_{n+1} = 0$. This $Q_{n+1} = 0$ is fed back to NOR gate-2 input thereby producing a 1 at its output; so $\overline{Q}_{n+1} = 1$, as originally assumed.

Next, let us assume that $Q_n = 1$ and $\overline{Q}_n = 0$. This 1 is applied to the input of NOR gate-2 and therefore the output becomes 0 (i.e., $\overline{Q}_{n+1} = 0$). This $Q_{n+1} = 0$ is fed to the input of NOR gate-1, thereby producing a 1 at its output; so $\overline{Q}_{n+1} = 1$, as originally assumed. Thus, the condition S = 0 and R = 0 will not affect the outputs of flip-flop.

Case 2 – The second input condition is S = 0 and R = 1. The 1 at the RESET input forces the output of NOR gate-1 Low (i.e., $Q_{n+1} = 0$). Now both the inputs of NOR gate-2 are 0 and its output $\overline{Q}_{n+1} = 1$. Thus, the input condition S = 0 and R = 1 will always ***reset*** the flip-flop to 0. When the reset input returns to 0, the flip-flop will remain in the 0 state.

Case 3 – The third input condition is S = 1 and R = 0, which forces the output of NOR gate-2 LOW i.e., $\overline{Q}_{n+1} = 0$. Now, both the inputs of NOR

gate-1 are 0, and therefore the output of NOR gate-1 is High i.e., $Q_{n+1} = 1$. Hence, the conditions S = 1 and R = 0 will always *set* the flip-flop to 1.

Case 4 – The last input condition is S = 1 and R = 1. This condition will produce 0 at the output of both the NOR gates. Hence. $Q_{n+1} = 0$ and $\overline{Q}_{n+1} = 0$. This condition violates the fact that the outputs Q_{n+1} and $\overline{Q}_{n+1}$ are the complements of each other. In normal operation, this condition must be avoided by making sure that 1's are not applied to both inputs simultaneously.

Table 5.16 NOR-based S-R Flip-flop

Inputs		*Outputs*		*Action*
S	***R***	Q_{n+1}	$\overline{Q}_{n+1}$	
0	0	Q_n	$\overline{Q}_n$	No change
0	1	0	1	Reset
1	0	1	0	Set
1	1	?	?	Forbidden

Q.42. Explain the NAND-based $\overline{S}$-$\overline{R}$ flip-flop with the help of circuit diagram and truth table.

Or

Describe the R-S-flip-flop using NAND gates with circuit diagram, truth table and waveforms. ***(R.G.P.V., June 2011)***

Ans. A basic flip-flop circuit constructed using cross-coupled NAND gates is shown in fig. 5.35. The operation of NAND $\overline{S}$-$\overline{R}$ flip-flop can be analyzed in the same manner employed for the NOR flip-flop. To understand the operation of NAND-based $\overline{S}$-$\overline{R}$ flip-flop, one must remember that a low at any input of a NAND gate will force its output high. The truth table for the NAND-based $\overline{S}$-$\overline{R}$ flip-flop is shown in table 5.17 which is different from that of a NOR-based S-R flip-flop. This flip-flop is called as $\overline{S}$-$\overline{R}$ flip-flop i.e., here $\overline{S}$ = 0 and $\overline{R}$ = 1 will set the flip-flop.

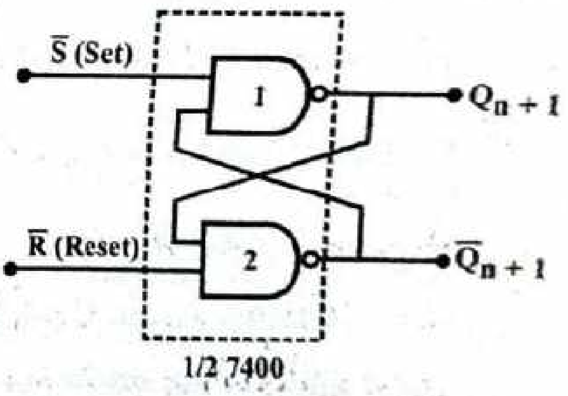


Fig. 5.35 NAND-based $\overline{S}$ - $\overline{R}$ Flip-flop

Case 1 – The first condition is $\overline{S}$ = 0 and $\overline{R}$ = 0. When both inputs go to 0, both outputs go to 1 i.e., $Q_{n+1} = 1$ and $\overline{Q}_{n+1} = 1$. This condition is ambiguous and should not be used.

Case 2 – The condition $\overline{S}$ = 0 and $\overline{R}$ = 1 always produces $Q_{n+1} = 1$

regardless of the present state of the flip-flop output. This condition sets the state of the flip-flop i.e., as shown $Q_{n+1} = 1$ and $\overline{Q}_{n+1} = 0$.

Case 3 – The condition $\overline{S} = 1$ and $\overline{R} = 0$ forces the lower NAND gate output to 1, i.e., $\overline{Q}_{n+1} = 1$. Now both the inputs of upper NAND gate are 1, and therefore the output of upper NAND gate is Low, i.e. $Q_{n+1} = 0$, regardless of the prior state of the flip-flop. This condition ***resets*** (clear) the flip-flop i.e., $Q_{n+1} = 0$ and $\overline{Q}_{n+1} = 1$.

Case 4 – The last condition $\overline{S} = 1$ and $\overline{R} = 1$, does not affect the state of the flip-flop. It remains in its prior state.

Table 5.17

Inputs		*Outputs*		*Action*
$\overline{S}$	$\overline{R}$	Q_{n+1}	$\overline{Q}_{n+1}$	
0	0	?	?	Forbidden
0	1	1	0	Set
1	0	0	1	Reset
1	1	Q_n	$\overline{Q}_n$	No change

Comparing the NAND flip-flop and the NOR flip-flop, we see that they operate basically in the same manner except for the following difference – The NOR flip-flop inputs are normally 0 and must be pulsed to the 1 state (active High) to change the state of the flip-flop outputs; the NAND flip-flop inputs are normally 1 and must be pulsed to the 0 state (active Low) to change the flip-flop output state.

Q.43. Write short note on R-S flip-flop. ***(R.G.P.V., Nov. 2018)***

Or

Explain the operation of R-S flip-flop. ***(R.G.P.V., June 2012)***

Or

Explain the R-S flip-flop. ***[R.G.P.V., Nov. 2018(O)]***

Ans. Refer the ans. of Q.40, Q.41 and Q.42.

Q.44. Explain the operation of clocked R-S flip flop with the help of logical diagram, truth table, symbol and characteristic equation.

(R.G.P.V., Dec. 2012)

Ans. The clocked S-R flip-flop which consists of two additional AND gates at the S and R impulses shown in fig. 5.36.

In this circuit, when the clock input is Low, the outputs of both the AND gates are LOW and the changes are S and R inputs will not affect the output (Q) of the flip-flop. When the clock input becomes HIGH, the value at S and

R inputs will be passed to the output of the AND gates and the output (Q) of the flip-flop will change according to the changes in S and R inputs as long as the clock input is HIGH. In this manner, one can strobe or clock the flip-flop so as to store either a 1 by applying S = 1, R = 0 (i.e., set) or a 0 by applying S = 0, R = 1 (i.e., reset) at any time and then hold that bit of information for any desired period of time by applying a LOW at the clock input. This flip-flop is called ***clocked S-R flip-flop.***

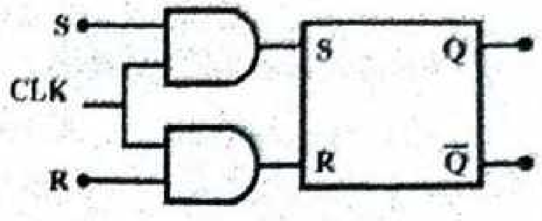


Fig. 5.36 Block Diagram of Clocked S-R Flip-flop

The clocked S-R flip-flop which consists of the basic NOR latch and two AND gates is shown in fig. 5.37.

A logic expression is called the characteristic equation of the S-R flip-flop.

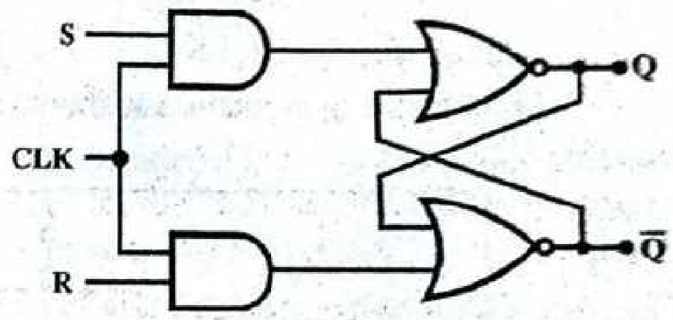


Fig. 5.37 Clocked NOR-based S-R Flip-flop

$$Q_{n+1} = S\overline{R} + \overline{R}Q_n$$

$$Q_{n+1} = (S + Q_n)\overline{R}$$

Q.45. With the help of circuit diagram, tables, explain the working of J-K flip-flop. Explain race around condition in J-K flip-flop.

(R.G.P.V., Jan./Feb. 2008)

Or

Explain the operation of J-K flip-flop. (R.G.P.V., June 2012)

Or

Draw the logic diagram for J-K flip-flop. Explain its operation.

(R.G.P.V., Feb. 2010, Dec. 2012)

Or

Draw and explain with the help of truth table working of J-K flip-flop.

(R.G.P.V., Dec. 2013)

Or

Draw the truth table of J-K flip-flop along with its logic diagram.

(R.G.P.V., June 2014)

Or

Explain in detail J-K flip-flop. (R.G.P.V., Dec. 2014)

Or

Write short note on J-K flip-flop. (R.G.P.V., May 2018)

Or

Explain the working of J-K flip-flop. (R.G.P.V., Nov. 2018)

Or

Explain the J-K flip-flop. *[R.G.P.V., Nov. 2018(O)]*

Ans. The uncertainty in the state of an R-S flip-flop when $R_n = S_n = 1$ (Fourth row of the truth table) can be eliminated by converting it into a J-K flip-flop. The data inputs are J and K which are ANDed with $\overline{Q}$ and Q, respectively, to obtain S and R inputs i.e.,

$$S = J.\overline{Q}$$
$$R = K.Q$$

Table 5.18 J-K Flip-flop

Inputs		*Output*
J_n	K_n	Q_{n+1}
0	0	Q_n
1	0	1
0	1	0
1	1	$\overline{Q}_n$

A J-K flip-flop thus obtained is shown in fig. 5.38. Its truth table is given in table 5.18.

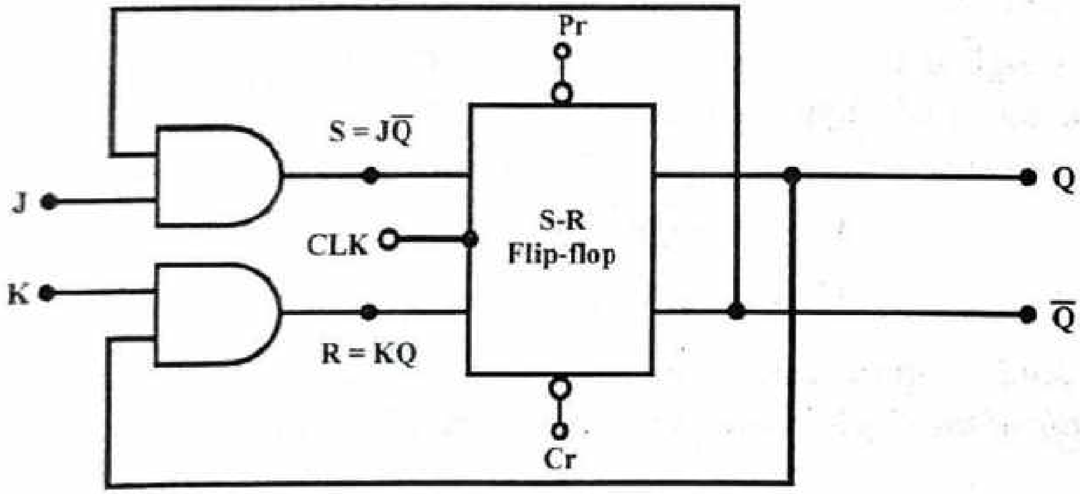


Fig. 5.38 J-K Flip-flop

The difficulty of both inputs 1 (S = R = 1) being not allowed in an S-R flip-flop is eliminated in a J-K flip-flop by using the feedback connection from outputs to inputs of the gates G_3 and G_4 (fig. 5.39). Table 5.18 assumes that the inputs do not change during the clock pulse (CLK = 1), which is not true because of the feedback connections.

Consider that the inputs are J = K = 1 and Q = 0, and a pulse as shown in fig. 5.40 (b) is applied at the clock input. After a time interval Δt equal to the propagation delay through two NAND gates in series output will change to Q = 1. Now if J = K = 1 and Q = 1 then the output will change back to Q = 0. Hence we conclude that for the duration t_p

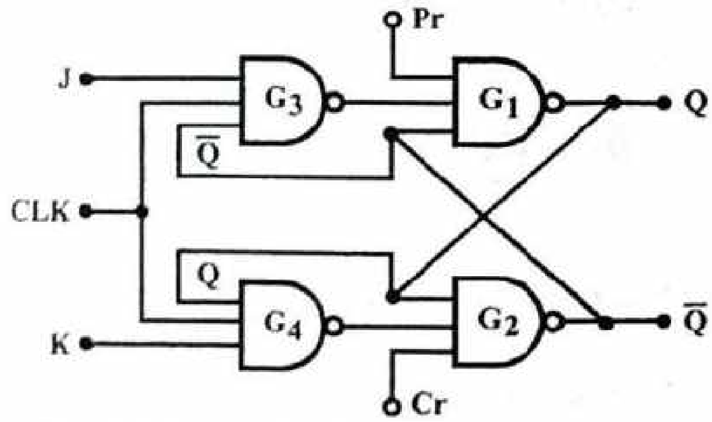
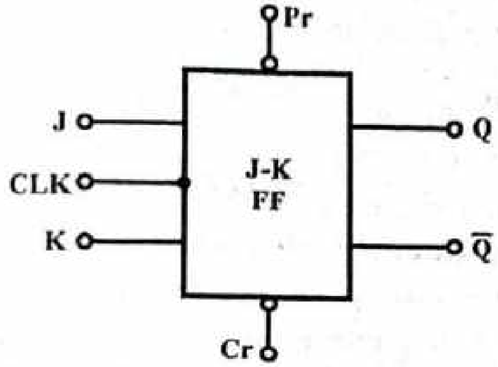
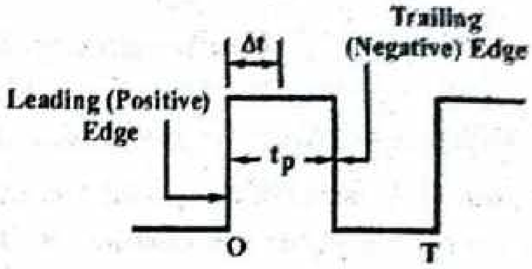


Fig. 5.39 A J-K Flip-flop using NAND Gates

of the clock pulse the output will oscillate back and forth between 0 and 1. At the end of clock pulse, the value of Q is uncertain. This situation is called ***race-around condition.***



(a) Logic Symbols of J-K Flip-flop



(b) A Clock Pulse

Fig. 5.40

The race-around condition can be avoided if $t_p < \Delta t < T$. However, it may be difficult to satisfy this inequality because of very small propagation delays in ICs. To overcome this difficulty a master-slave (M-S) J-K flip-flop is used.

Q.46. Differentiate between level and edge triggering. Draw the logic circuit and truth table for J-K flip-flop. ***(R.G.P.V., May 2019)***

Ans. Difference between level and edge triggering is as follows –

S.No.	*Level Triggering*	*Edge Triggering*
(i)	In the level triggering, the output state is allowed to change according to input(s) when active level (either positive or negative) is maintained at the enable input.	In the edge triggering, the output responds to the changes in the input only at the positive or negative edge of the clock pulse at the clock input.
(ii)	It is sensitive to glitches. Example – Latch	It is not sensitive to glitches. Example – flip-flop

J-K flip-flop – Refer the ans. of Q.45.

INTRODUCTION TO SEMICONDUCTORS, DIODES, V-I CHARACTERISTICS

Q.47. What is meant by semiconductor ? Give its types.

Ans. The materials, whose electrical properties lie between those of conductors and insulators, are known as semiconductor. The examples of such materials are Germanium (Ge), Silicon (Si), Gallium Arsenide (GaAs), Cadmium Sulphides (CdS), Lead Telluride etc.

The semiconductors are of mainly two types –

(i) Intrinsic semiconductor

(ii) Extrinsic semiconductor.

Q.48. Name any three material which are most widely used as semiconductors. ***(R.G.P.V., Dec. 2011)***

Ans. The most commonly used semiconductor materials are –

(i) Germanium (ii) Silicon (iii) Gallium arsenide.

Q.49. What is intrinsic semiconductor ? ***(R.G.P.V., Dec. 2011)***

Or

Define the intrinsic semiconductor. ***(R.G.P.V., June 2012)***

Ans. A semiconductor, which is in its extremely pure form, is known as an intrinsic (or pure) semiconductor. The nature of semiconductors is such that even a small amount of certain impurities can change their electrical properties drastically. It is due to this fact, that a semiconductor would not be called truly intrinsic, unless the impurity level is very small.

Q.50. What do you understand by intrinsic and extrinsic semiconductors? ***(R.G.P.V., Dec. 2010)***

Or

Differentiate between intrinsic and extrinsic semiconductor. ***(R.G.P.V., June 2013)***

Ans. **Intrinsic Semiconductor** – Refer the ans. of Q.49.

Extrinsic Semiconductor – When a small quantity of impurity is mixed in a pure or intrinsic semiconductor, the conductivity of semiconductor increases. Such an impure semiconductor is called the extrinsic semiconductor. The conductivity of resultant crystal depends on the nature and quantity of the impurity added. Depending upon the nature of impurity added in intrinsic semiconductor.

The extrinsic semiconductor are of two types –

(i) N-type or donor (ii) P-type or acceptor.

Q.51. Define the doping. ***(R.G.P.V., June 2012)***

Or

What is doping ? ***(R.G.P.V., Dec. 2011)***

Ans. Addition of impurity atoms to intrinsic semiconductor crystal is called the doping and the impurity used for doping is called the dopant.

Q.52. What type of semiconductor results when silicon is doped with (a) donor impurities (b) acceptor impurities ? ***(R.G.P.V., Dec. 2011)***

Ans. (a) Arsenic, antimony and phosphorous or any other pentavalent impurity used as dopant to produce an N-type semiconductor is called the donor type impurity.

(b) Boron, gallium and indium or any other trivalent impurity used as dopant to produce a P-type semiconductor is called the acceptor type impurity.

Q.53. Define the forbidden energy gap. ***(R.G.P.V., June 2012)***

Ans. The energy gap between the valence band and conduction band is known as forbidden energy gap. This gap is a region in which no electron can stay as there is no allowed energy state. The greater the forbidden energy gap more tightly the valence electrons are bound to the nucleus.

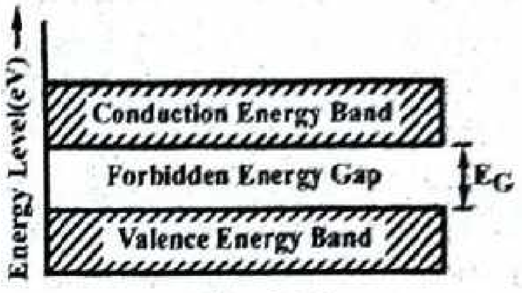


Fig. 5.41

Q.54. Define the charge carriers. ***(R.G.P.V., June 2012)***

Ans. Current conduction in an N-type semiconductor is due to excess of free electrons whereas in a P-type semiconductor it is due to excess of holes. Free electrons in N-type semiconductors and holes in P-type semiconductors are charge carriers.

Q.55. Explain the formation of n-types of semiconductor.

Ans. If pentavalent impurity atom (such as Antimony, Arsenic, Phosphorus etc.) is added to the pure Germanium crystal, the crystal so obtained is called the n-type semiconductor. Out of the five valence electrons of Antimony atom, four electrons form covalent bonds with valence electrons of four Germanium atoms and the fifth valence electron remains bound with a very small energy (≈ 0.01 eV) as shown in fig. 5.42. Thus, the fifth valence electron of impurity atom can be made free by importing nearly 0.01 eV energy. Since a free electron in obtained which acts as the charge carrier, the crystal is called n-type. The pentavalent impurity atom is called the donor since it donates free electron to the crystal. In n-type semiconductor, majority charge carriers are the electrons and minority charge carriers are the holes.

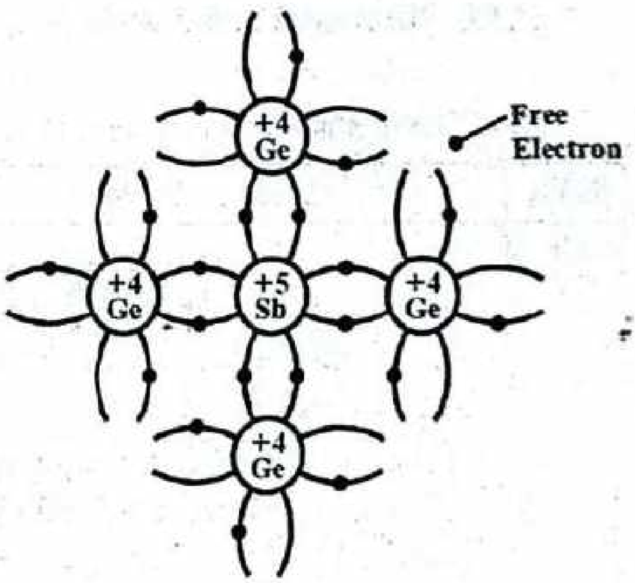


Fig. 5.42

Q.56. Explain the formation of p-types of semiconductor.

Ans. If trivalent impurity atom (such as Boron, Indium etc.) is mixed with pure Germanium crystal, the crystal so obtained is called the p-type semiconductor. The three valence electrons of Indium atom form covalent bonds with the valence electrons of three neighbouring Germanium atoms and there remains lack of one electron for the rhombohedral covalent shape (fig. 5.43). This lack of one electron is called the hole.

This hole soon captures an electron from its neighbouring Germanium atom and a hole is created in this neighbouring atom. Thus, holes become available for movement from one place to the other inside the crystal. If the hole moves to the right, the electron moves to the left. Thus hole is equivalent to a positively charged particle. Since positive holes are responsible to increase conductivity in this crystal, the crystal so obtained is called the p-type crystal and the impurity atom is called the acceptor.

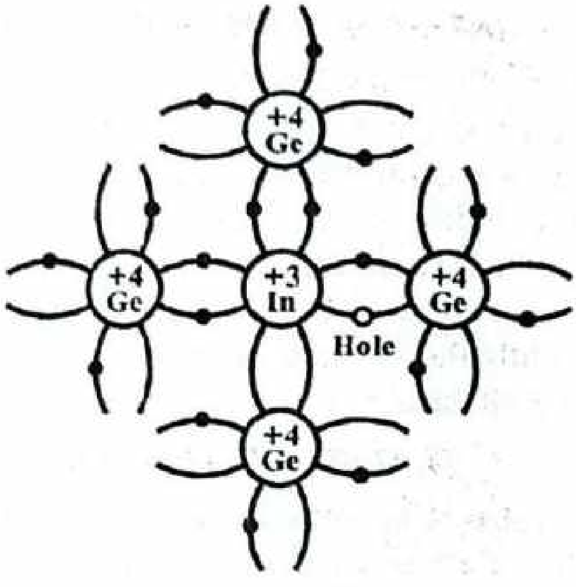


Fig. 5.43

In a p-type semiconductor, the majority charge carriers are the holes and the minority charge carriers are the electrons.

Q.57. Distinguish between P-type and N-type materials.
(R.G.P.V., June 2012)

Ans. Refer the ans. of Q.55 and Q.56.

Q.58. Distinguish between the semiconductor and insulator.
(R.G.P.V., June 2012)

Ans. Distinguish between semiconductor and insulator are as follows –

S.No.	*Semiconductor*	*Insulator*
(i)	At low temperature there is no electric conduction in them, but at high temperature electric conduction becomes possible in them.	In insulator no electrical conduction is possible.
(ii)	These have neither a very large number nor a very small number of current carriers free electrons.	The number of free electrons in an insulator is very small.
(iii)	The forbidden energy gap between the conduction band and valence band is nearly 1 eV.	The forbidden energy gap is large, for diamond the gap energy is about 6 eV.
(iv)	A semiconductor has more conductivity.	An insulator has less conductivity.

Q.59. Differentiate between conductor, semiconductor and insulator with example.
(R.G.P.V., Dec. 2014)

Ans. Difference between Conductors and Semiconductors are as follows –

S.No.	Conductor	Semiconductor
(i)	Electric conduction is possible in them.	At low temperature there is no electric conduction in them, but at high temperature electric conduction becomes possible in them.
(ii)	These have a very large number of current carriers free electrons.	These have neither a very large number nor a very small number of current carriers free electrons.
(iii)	The resistance of conductors increases with increase in temperature, i.e., their temperature coefficient of resistance is positive.	The resistance of semiconductors decreases with increase in temperature, i.e., the temperature coefficient of resistance is negative.
(iv)	On adding impurities, their conductivity decreases.	On adding impurities, their conductivity increases.
(v)	These have a very small resistivity ($\approx 10^{-6}$ Ω-m).	These have resistivity nearly 0.1 Ω-m.
(vi)	The forbidden energy gap between the conduction band and valence band is nearly zero.	The forbidden energy gap between the conduction band and valence band is nearly 1 eV.
(vii)	Examples – metals, human body, earth etc.	Examples – Silicon, Germanium etc.

Also refer the ans. of Q.58.

Q.60. Define ideal diode and practical diode. ***(R.G.P.V., Dec. 2014)***

Ans. The ideal diode is a perfect two-state device which exhibits zero impedance when forward biased and infinite impedance when reverse biased. Since either current or voltage is zero at any instant, no power is dissipated by an ideal diode.

On the other hand, practical diodes have not zero impedance when forward biased and do not exhibit infinite impedance when reverse biased.

Q.61. Why silicon is usually preferred over germanium for fabrication semiconductor devices ? ***(R.G.P.V., June 2014)***

Ans. Although both silicon and germanium are used in semiconductor devices, the present day trend is to use silicon. The main reasons for this are –

(i) Smaller I_{CBO} – At room temperature, a silicon crystal has fewer free electrons than a germanium crystal. This implies that silicon will have much smaller collector cut-off current (I_{CBO}) than that of germanium. In general, with germanium I_{CBO} is 10 to 100 times greater than with silicon. The typical value of I_{CBO} at 25°C for small signal transistors are –

Silicon – 0.01 μA to 1 μA

Germanium – 2 to 15 μA

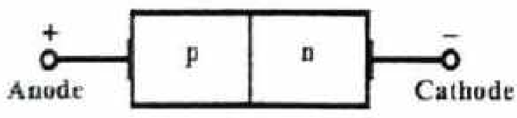
(ii) Smaller Variation of I_{CBO} with Temperature – The variation of I_{CBO} with temperature is less than in silicon as compared to germanium. A rough rule of thumb for germanium is that I_{CBO} approximately doubles with each 8 to 10°C rise while in case of silicon, it approximately doubles with each 12°C rise.

(iii) Greater Working Temperature – The structure of germanium will be destroyed at a temperature of approximately 100°C. The maximum normal working temperature of germanium is 70°C but silicon can be operated up to 150°C. Therefore, silicon devices are not easily damaged by excess heat.

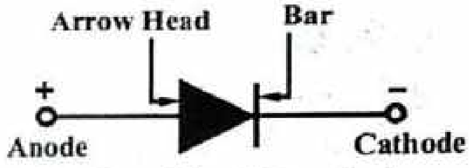
Q.62. What is a p-n diode ? ***(R.G.P.V., April 2009)***

Ans. If p-type and n-type semiconductors are taken separately, they are of little use in actual practice. If we join a piece of p-type semiconductor to a piece of n-type semiconductor such that the crystal structure remains continuous at the boundary as depicted in fig. 5.44 (a), a p-n junction is formed which is a very useful device. Such as p-n junction is known as a ***semiconductor diode, p-n junction diode*** or simply a ***crystal diode***.

The circuit symbol of a semiconductor diode is shown in fig. 5.44 (a) and the graphical symbol is shown in fig. 5.44 (b). The arrow in the symbol indicates the direction of conventional current flow when the diode is forward biased i.e., from the positive terminal through the device to the negative terminal. The p-side of the diode is always the positive terminal for forward bias and is called the ***anode***. The n-side is known as the ***cathode*** and is the negative terminal when the device is forward biased.



(a) Circuit Symbol



(b) Graphical Symbol

Fig. 5.44 p-n Junction Diode

Q.63. Explain the barrier potential with reference to a semiconductor diode. ***(R.G.P.V., Jan./Feb. 2008, June 2010)***

Ans. The depletion layer of a p-n junction has no mobile charge carriers. But it contains fixed rows of oppositely charged ions on its two sides. Because of this charge separation, an electric potential (denoted by V_B) is established across the junction, even when the junction is not connected to any external voltage source as shown is fig. 5.45. This electric potential is called ***barrier*** or ***junction potential***. It will be interesting to know that this barrier potential exerts a

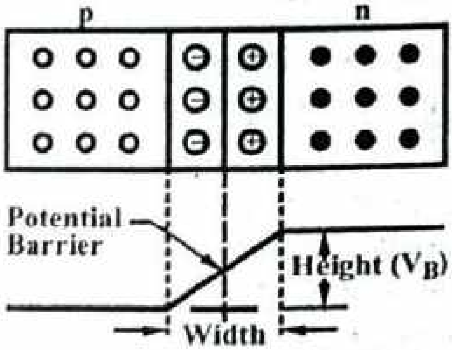


Fig. 5.45 Junction or Barrier Potential

repelling force on the mobile charge carriers, trying to crossover the junction. This force stops the mobile charge carriers to crossover the junction, unless the energy is supplied from an external source. At the room temperature (300° K), the value of V_B is 0.6 V for Silicon and 0.2 V for Germanium.

Q.64. Explain the depletion layer with reference to a semiconductor diode. ***(R.G.P.V., Jan./Feb. 2008, June 2010)***

Ans. We know that as soon as the p-n junction is formed, some of the holes in p-region and the free electrons in the n-region diffuse in each other and disappear due to recombination. In this process, the negative acceptor ions in the p-region and positive donor ions in the n-region are left uncovered in the vicinity of junction as shown in fig. 5.46. The additional holes, trying to diffuse to the n-region, are repelled by the uncovered positive charge of the donor ions. Similarly, the electrons, trying to diffuse into the p-region, are repelled by the uncovered negative charge of the acceptor ions. As a result of this, the further diffusion of free electrons and holes across the junction is stopped. The region containing the uncovered acceptor ions, in the vicinity of the junction, is called depletion region. Moreover, as the uncovered charges within the depletion region exists in the form of parallel rows or plates of opposite charges, therefore, it is known as depletion layer.

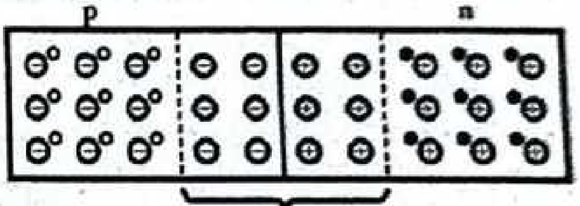


Fig. 5.46

Q.65. Explain the behaviour of a p-n junction under the unbiased, forward biased and reverse biased conditions. ***(R.G.P.V., Sept. 2009)***

Ans. The behaviour of the p-n junction under the different biasing conditions –

(i) Unbiased – A p-n junction, across which no external voltage source is connected, is known as ***unbiased*** p-n junction. Now, consider such an unbiased p-n junction as shown in fig. 5.47. We know that immediately after the formation of a p-n junction, a depletion layer is formed in the vicinity of junction. Because of this, there exists a barrier potential (V_B), which stops the further diffusion (or crossover) of carriers across the junction.

The significance of V_B is that, a hole in the P-region requires an energy (equal to $q.V_B$) in order to crossover the junction. Similarly an electron in the N-region requires the same amount of energy (equal to a V_B) in order to crossover the junction. If the junction is at room temperature, thermal energy is added

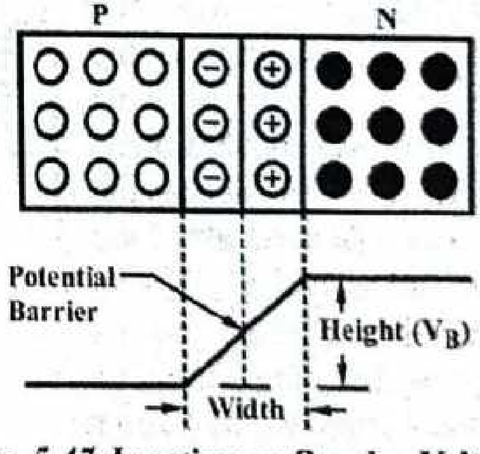


Fig. 5.47 Junction or Barrier Voltage

continuously. As a result of this, few holes and electrons will acquire enough energy to get over the potential barrier, and diffuse the junction. Since the diffusion of electrons and holes is opposite in direction, therefore, there is a single current across the junction. This component of current is called a current due to majority carriers or simply majority carrier current.

There is another component of current, which flows through the junction. This current is due to the diffusion of minority carriers across the junction. We know that thermal energy causes electron hole pairs to be generated within the semiconductor materials. Such electron-hole pairs are assisted in diffusing across the junction by barrier potential (V_B). The current produced due to the diffusion of minority carriers, across the junction is called minority carrier current. The minority carrier current flows in a direction opposite to that of the majority carrier current. In an unbiased p-n junction, the majority carrier current and minority carrier current are equal in magnitude and flow in opposite direction. It is thus obvious, that there is no net flow of current across the junction.

(ii) Forward Biased Condition – If we connect voltage source to the p-n junction such that the positive terminal is connected to the P-region and negative terminal to the N-region, the p-n junction is said to be forward biased as shown in fig. 5.48.

When a p-n junction is forward biased as shown in fig. 5.48 (a) the holes are repelled by the positive terminal of the voltage source and are forced to move towards the junction. Similarly, the electrons are repelled by the negative terminal of the voltage source and move towards the junction. Because of their acquired energy (from the voltage source), some of the holes and electrons enter the depletion layer and recombine themselves. This reduces the width as well as height of the potential barriers (V_B) as shown in fig. 5.48 (b). In other words, the width of depletion layer and the barrier potential reduces with the

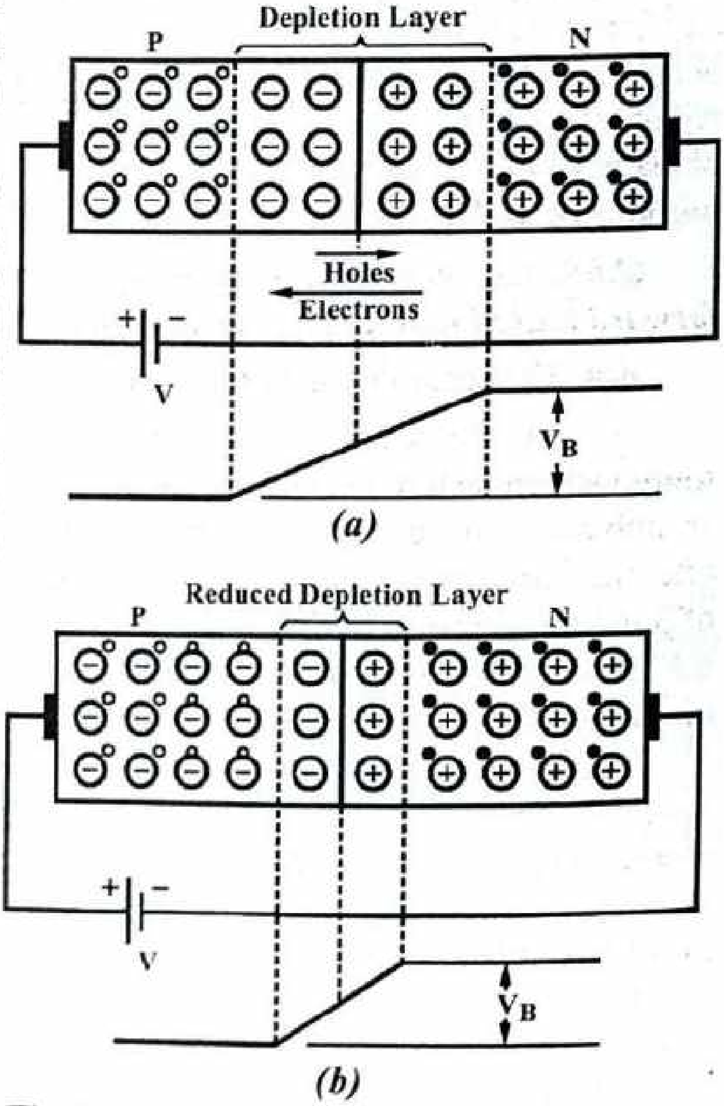


Fig. 5.48 p-n Junction with Forward Biased

forward bias. As a result of this, more majority carriers diffuse across the junction therefore, it causes a large current to flow through the p-n junction.

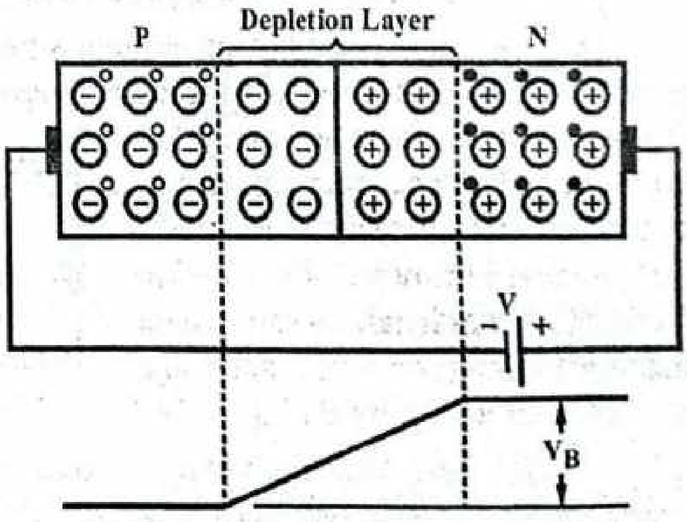
It may be noted that for each recombination of free electron and hole, which occurs, an electron from the negative terminal of the voltage source enters the N-type region. Then it moves towards the junction. Similarly, in the P-type region near the positive terminal of the voltage source, an electron breaks a covalent bond in the crystal and enters the positive terminal of the voltage source. Thus for each electron, which breaks its bond, a hole is created. This hole drifts towards the junction. The current through the external circuit, is due to the movement of electrons only. On the otherhand, the current within the p-n junction is the sum of electron current (in the N-region) and hole current (in the P-region).

The current in the external circuit continues to flow as long as the voltage source is present in the circuit. The current increases with the increase in applied voltage and is of the order of several milliamperes. The maximum value of current depends upon the actual resistance, called bulk resistance of the semiconductor material.

(iii) Reverse Biased Condition – If we connect a voltage source to a p-n junction, such that positive terminal of the voltage source is connected to the N-region and negative to the P-region then the p-n junction is said to be reverse biased. Fig. 5.49 shows a reverse biased p-n junction.

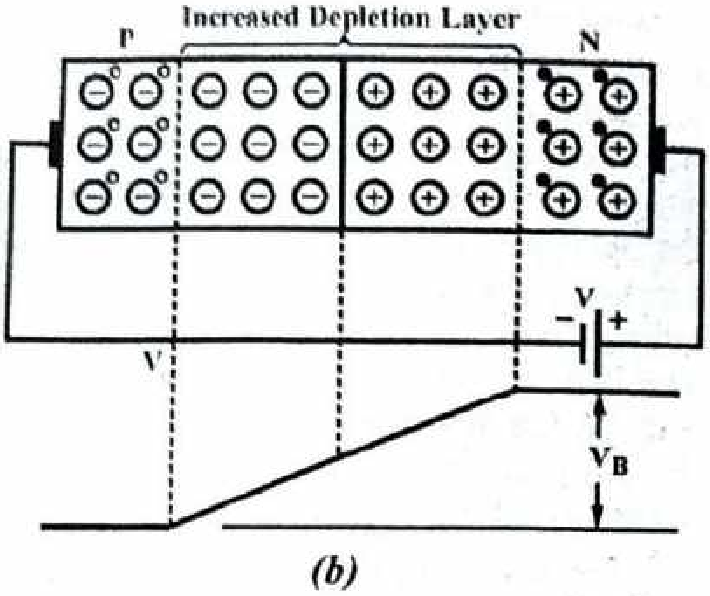
When a p-n junction is reverse biased as shown in fig. 5.49 (a), the holes in the P-region are attracted towards the negative terminal of the voltage source. And the electrons in the N-region are attracted to the positive terminal of the voltage source. Thus the majority carriers are drawn away from the junction. This widens the depletion layer and increases the barrier potential as shown in fig. 5.49 (b).

The increased barrier potential makes it very difficult for the majority carriers to diffuse across the junction thus there is no current due to majority carriers in a reverse biased p-n junction. In other words, the junction offers very high resistance under reverse biased condition. However, the barrier potential helps the minority carriers in crossing the junction. As a matter of fact, as soon as a minority carrier is generated it is swept (i.e., drifted) across the junction because of the barrier potential. Hence a small amount of current does flow through the reverse biased p-n junction. The amount of this



(a)

current depends upon the generation of minority carriers within the P-region and N-region. It may be noted that generation of minority carriers is dependent upon the temperature and is independent of the applied reverse voltage. Therefore, the current, due to the flow of minority carriers, remains the same whether the applied voltage is increased or decreased. Because of this reason, the current is known as reverse saturation current.



(b)

Fig. 5.49 p-n Junction with Reverse Biased

Q.66. Discuss the behaviour of P-N junction diode under forward and reverse biasing. ***(R.G.P.V., Dec. 2010)***

Or

Explain operation of P-N junction diode when it is –
(i) Forward bias (ii) Reverse bias. ***(R.G.P.V., Dec. 2013)***

Ans. Refer the ans. of Q.65 (ii) and (iii).

Q.67. Draw and explain voltage-current characteristics of P-N junction. ***(R.G.P.V., June 2011)***

Or

Draw the V-I characteristics of a germanium diode. Explain the same. ***(R.G.P.V., Dec. 2012)***

Or

Discuss V-I characteristic of P-N diode. ***(R.G.P.V., June 2013)***

Or

Draw and explain the V-I characteristic of diode.(R.G.P.V., Dec. 2014)

Ans. The curve between voltage across the junction and the circuit current is known as the volt-ampere or ***V-I characteristic of a p-n junction***. The voltage is taken on the X-axis and current on the Y-axis. The circuit arrangement to determine the V-I characteristics of a p-n junction is shown in fig. 5.50. The study of the characteristics can be done in three headings; zero external voltage, forward bias and reverse bias.

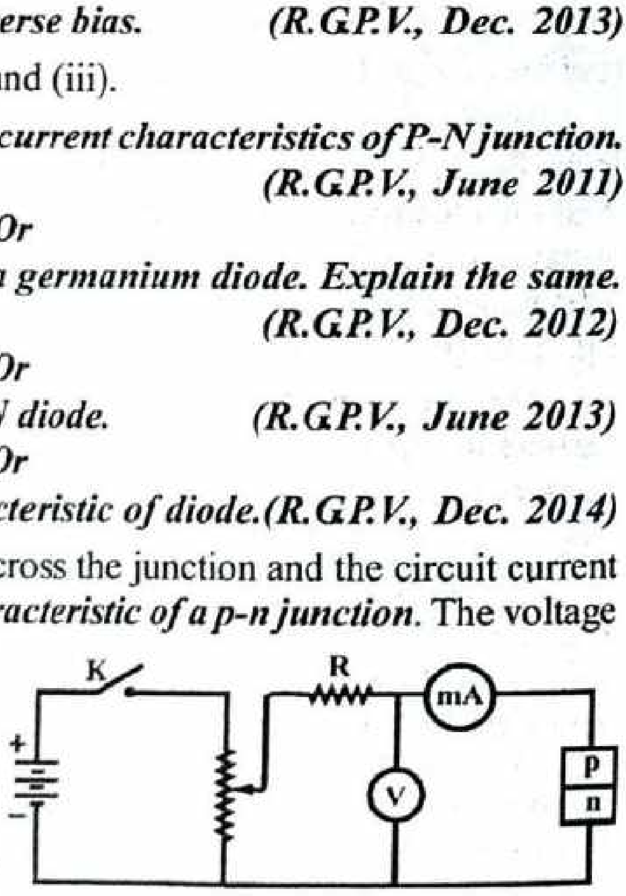


Fig. 5.50

(i) Zero External Voltage – At the zero external voltage i.e., circuit is open at K, the potential barrier does not allow current flow at the junction. Hence, the current is zero in the circuit as shown by point O in fig. 5.51.

(ii) Forward Bias – On applying forward bias to the p-n junction, the potential barrier is reduced. The potential barrier is completely eliminated at some forward voltage (0.7 V for Si and 0.3 V for Ge) and current flow starts in the circuit. Now, when forward voltage is increased, the current increases. Hence, an increasing curve OB is obtained with forward bias as shown in fig. 5.51. On seeing the forward characteristic, it is found that in the region OA, the current rises very slowly and the curve is non-linear. The reason behind it is that the external applied voltage is used up in overcoming the potential barrier. But, as soon as the external voltage exceeds the potential barrier voltage, the p-n junction behaves the same as an ordinary conductor. Hence, the current increases very sharply with rise in external voltage (region AB on the curve). The curve is almost linear.

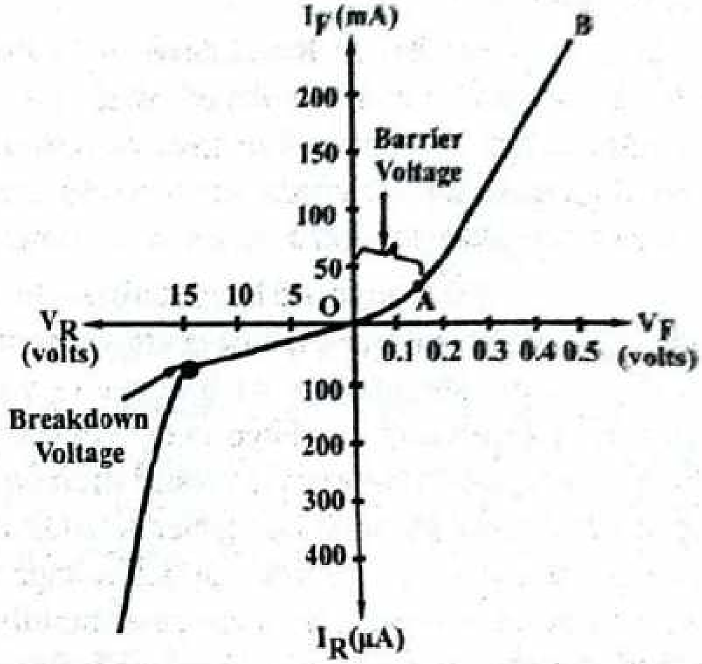


Fig. 5.51

(iii) Reverse Bias – On applying reverse bias to the p-n junction, the potential barrier is increased at the junction. Hence, there is very high junction resistance and current does not flow through the circuit practically. But, in practice, a very small current flows in the circuit in reverse bias, as indicated in the reverse characteristic. This is known as ***reverse saturation current (I_s)*** and it flows because of minority carriers. As shown in fig. 5.52, when reverse bias is applied, it appears as forward bias to the minority carriers. Hence, there is a very small current flow in the reverse direction.

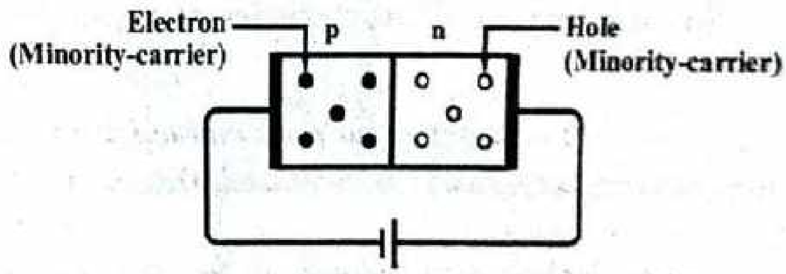


Fig. 5.52

If the reverse voltage is continuously raised, the kinetic energy of electrons (minority-carriers) may become so high that these minority-carriers knock out electrons from the semiconductor atoms. The breakdown of the junction happens at this stage. There is a sudden rise of reverse current and a great fall of the resistance of barrier region. This may permanently destroy the junction.

p-n junction allows a very small amount of current when it is reverse biased. It is due to movement of minority carriers across the junction and is independent of the applied reverse voltage. If the reverse bias is increased to a large value, the current through the junction increase abruptly. Voltage at which this action occurs is known as ***breakdown voltage***. At this voltage crystal structure breaks down. The following to processes cause junction breakdown due to the increase in reverse voltage –

(a) Zener Breakdown – In this case, breakdown occurs in junctions, which are heavily doped. When the reverse voltage is increased, the electric field at the junction also increases. A strong electric field causes a covalent bond to break from the crystal structure. As a result a large number of minority carriers are generated and a large current flows through the junction.

(b) Avalanche Breakdown – In this case, the increased reverse voltage increases the amount of energy imparted to minority carriers as they diffuse across the junction. As the reverse voltage is increased, further, the minority carriers acquire a large amount of energy. When these carriers collide with silicon atoms, within the crystal structure they impart sufficient energy to break a covalent bond and generate additional carriers. These additional carriers pickup energy from the applied voltage and generate still more carriers. As a result the reverse current increases rapidly. This cummulative process of carrier generation is known as ***avalanche breakdown***.

Q.68. What is a p-n junction diode ? Sketch the V-I characteristics. ***(R.G.P.V., Dec. 2017)***

Ans. Refer the ans. of Q.62 and Q.67.

Q.69. Explain the forward and reverse bias operation and voltage-current characteristics of a p-n junction diode. ***(R.G.P.V., Dec. 2011)***

Ans. **Forward and Reverse Bias Operation** – Refer the ans. of Q.65.

Voltage-current Characteristics of a p-n Junction Diode – Refer the ans of Q.67.

Q.70. What happens to the conductivity of the semiconductor and a metal when temperature is increased. Discuss with reason. ***(R.G.P.V., Dec. 2012)***

Ans. Conductivity denoted by (σ), the conductivity (σ) of an intrinsic semiconductor depends upon the number of hole-electron pairs and mobility. The number of hole-electron pairs increases with the rise in temperature, and its mobility decreases. However, the conductivity of an intrinsic semiconductor increases with the increase in temperature. The conductivity at any temperature ($T^\circ K$) is given by

$$\text{Conductivity } (\sigma) = \sigma_0[1 + \alpha (T - T_0)]$$

Here, α = Temperature coefficient.

The conductivity of extrinsic semiconductor decreases with the increase in temperature, as the number of majority carriers is almost constant and mobility decreases.

When a metal is considered, its conductivity is also not a constant value with respect to temperature. It varies with temperature. The conductivity decreases with increase in temperature in a metal. Increase of temperature in metal results in greater thermal agitation of the ions and this results in decrease of mean free path of the free electrons. Since mean free path depends on the mobility of the material, the mobility decreases. The conductivity of the metal is directly proportional to the mobility and thus the conductivity decreases. Thus, the resistance of the metal increases with increase in temperature.

Q.71. Explain the following –
(i) P-type and N-type semiconductor
(ii) Half wave and full wave rectifier. ***(R.G.P.V., Dec. 2017)***

Ans. (i) P-type and N-type Semiconductor – Refer the ans. of Q.55 and Q.56.

(ii) Half Wave and Full Wave Rectifier – Half wave rectifier converts an A.C. voltage into a pulsating D.C. voltage using only one half of the applied A.C. voltage. The rectifying diode conducts during one half of the A.C. cycle only.

Fig. 5.53 shows the basic circuit of half wave rectifier. In half wave rectifier, the conduction of current takes place only during the positive half-cycles of input A.C. supply. The negative half-cycles of A.C. supply are suppressed i.e., during negative half-cycles no current is conducted and hence no voltage appears across the load. Since in a rectifier circuit the input $V_i = V_m \sin \omega t$ has a peak value V_m which is very large compared with the cut-in voltage of the diode. A single crystal diode acts as a half wave rectifier. The transformer allows two advantages such as step-up or step-down the A.C. input voltage as the situation requirement. Transformer isolates the rectifier circuit from power line and thus the risk of electric shock.

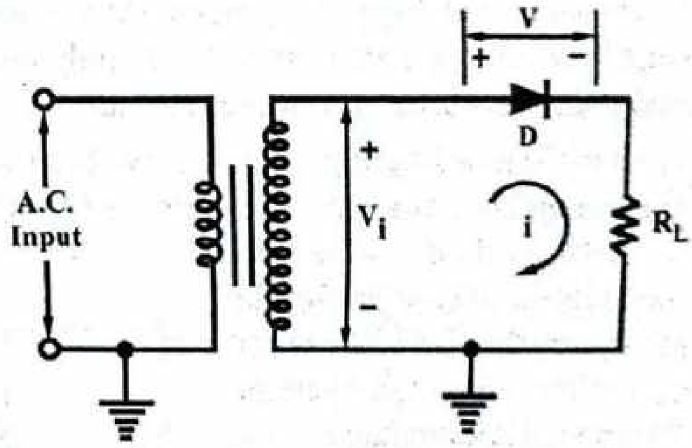


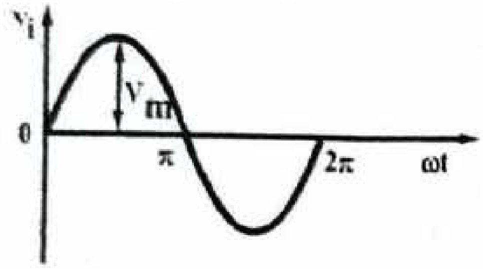
Fig. 5.53 Basic Circuit of Half Wave Rectifier

With the diode idealized to be a resistance R_f in the ON state and an open circuit in the OFF state, the current 'i_L' in the diode or load R_L is given by

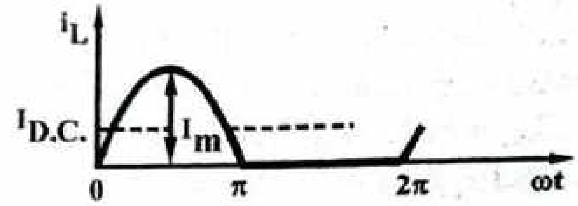
$$i_L = \begin{cases} I_m \sin \omega t, & \text{for } 0 \le \omega t \le \pi \\ 0, & \text{for } \pi \le \omega t \le 2\pi \end{cases} \quad \ldots(i)$$

and
$$I_m = \frac{V_m}{R_f + R_L} \qquad ...(ii)$$

The transformer secondary voltage (V_i) is shown in fig. 5.54 (a) and the rectified current in fig. 5.54 (b). Note that the output current is unidirectional.



(a) Waveform of Transformer Sinusoidal Secondary Voltage (V_i)



(b) Diode and Load Current (i_L)

Fig. 5.54

During the positive half-cycle of the A.C. voltage, the diode D is forward biased (or ON) and conducts. While conducting the diode acts as a short circuit so that circuit current flows and hence A.C. input voltage positive half-cycle is dropped across the load resistance R_L and constitute the output voltage V_L as shown in output waveform of the load voltage.

But during the negative input half-cycle, the diode is reverse biased (or OFF) and it does not conduct i.e., there is no current flow. Hence, there is no voltage drop across R_L. So, negative half-cycle is not used for delivering power to the load. The output is not a steady D.C. but only a pulsating D.C. wave having a ripple frequency equal to that of the input voltage frequency. This wave can be observed by an oscilloscope connected across the load R_L. When measured by a D.C. meter then it will show some average positive values for voltage and current. Since only one half-cycle of the input wave is used thus it is called half wave rectifier.

Full Wave Rectifier – Full wave rectifier converts an A.C. voltage into a pulsating D.C. voltage using both half cycles of the applied A.C. voltage. It is used two diodes of which conducts during one half-cycle while the other diode conducts during the other half-cycle of the applied A.C. voltage.

Fig. 5.55 shows the basic circuit of full wave centre-tap rectifier.

This circuit comprises two half wave rectifier circuits, so connected that conduction takes place through one diode

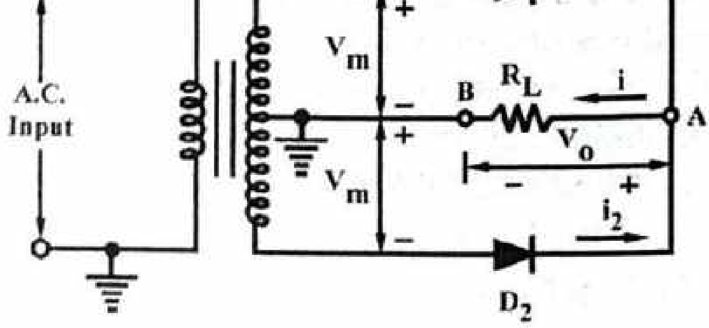
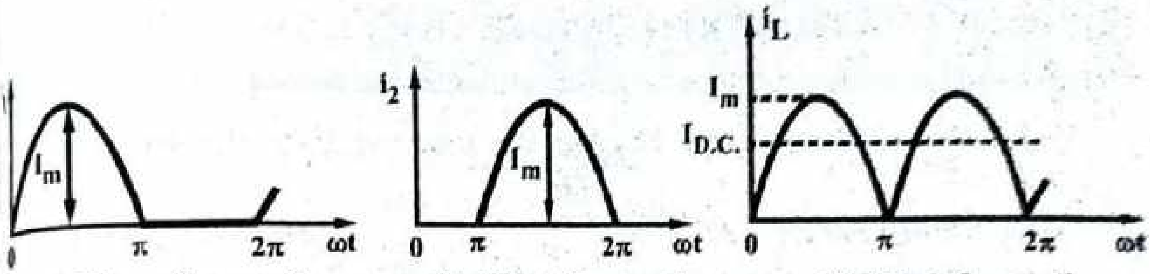


Fig. 5.55 Basic Circuit of Full Wave Centre-tap Rectifier

during one half of the power cycle and through the other diode during the second half of the cycle. The waveform of individual diode currents and the load current i_L are shown in figs. 5.56 (a), (b) and (c).

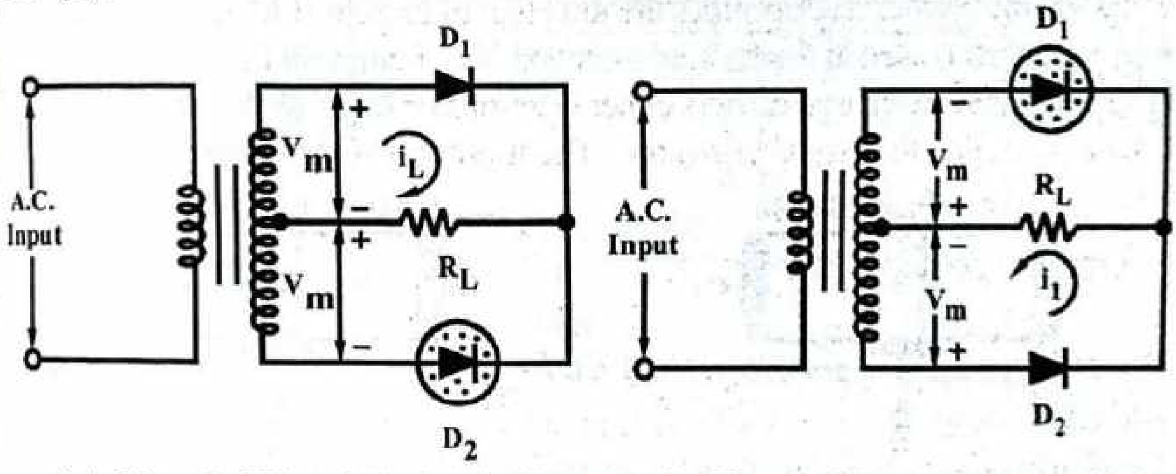


(a) Waveform of Current (i_1) *(b) Waveform of Current (i_2)* *(c) Waveform of Load Current (i_L)*

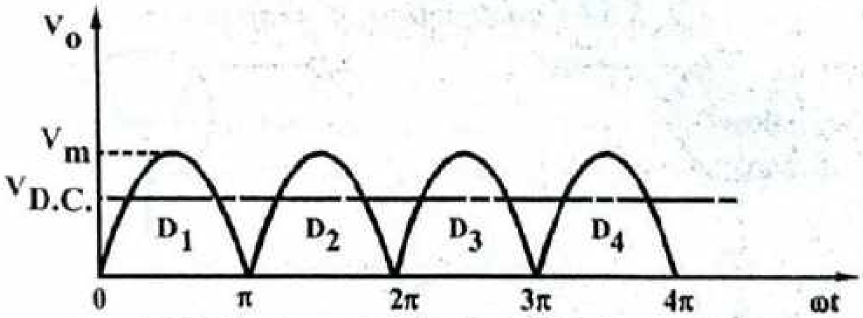
Fig. 5.56

The centre-tap full wave rectifier circuit contains two diodes D_1 and D_2. During the positive half-cycles of transformer secondary voltage, the diode D_1 is forward biased and diode D_2 is reverse biased.

The current flows through the diode D_1, load resistor R_L and the upper half of the winding as shown in fig. 5.57 (a). During negative half-cycles, diode D_2 becomes forward biased and diode D_1 reverse biased. The current flows through diode D_2, load resistor R_L and lower half of the winding as shown in fig. 5.57 (b). The waveform of the load voltage V_o is shown in fig. 5.57 (c).



(a) Circuit When Diode D_1 ON *(b) Circuit When Diode D_2 ON*



(c) Waveform of the Load Voltage (V_o)

Fig. 5.57

Q.72. Explain the working of a full wave rectifier. (R.G.P.V., May 2019)

Ans. Refer the ans. of Q.71 (ii).

BIPOLAR JUNCTION TRANSISTORS (BJT) & THEIR WORKING

Q.73. What is transistor ? Explain the construction of transistor.

Or

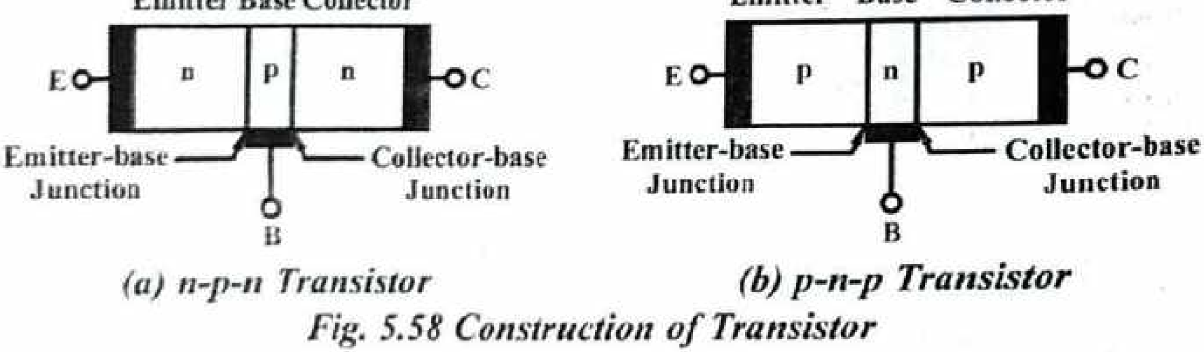
Write short note on BJT. (R.G.P.V., May 2019)

Ans. A bipolar junction transistor is a three terminal semiconductor devices in which the operation depends on the interaction of both majority and minority carriers and hence the name bipolar.

A transistor is basically a Silicon or Germanium crystal in which a layer of n-type Silicon is sandwiched between two layers of p-type Silicon. Alternatively, a transistor may consist of a layer of p-type Silicon sandwiched between two layers of n-type Silicon. The transistor in first case is referred to as p-n-p transistor and in the second case as n-p-n transistor.

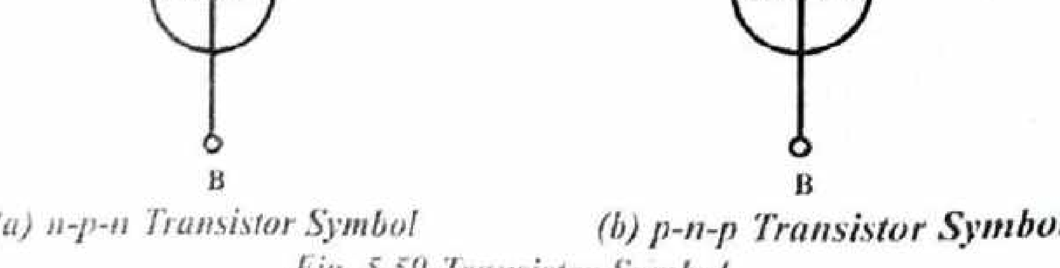
Construction – Essentially a transistor has three regions called Emitter (E), Base (B) and Collector (C) respectively. A brief description of these three regions is given below –

(i) Emitter – It is a region situated in one side of the transistor. The arrow on the emitter lead specifies the direction of current flow when the emitter-base junctions biased in the forward direction. The main function of this region is to supply majority charge carriers either electrons or holes to the base and thus it is heavily doped than to other regions. The n-p-n transistor construction and the



(a) n-p-n Transistor *(b) p-n-p Transistor*

Fig. 5.58 Construction of Transistor



(a) n-p-n Transistor Symbol *(b) p-n-p Transistor Symbol*

Fig. 5.59 Transistor Symbol

n-p transistor construction are shown in fig. 5.58 (a) and (b) respectively. The symbols of n-p-n and p-n-p transistor are shown in fig. 5.59 (a) and (b) respectively.

(ii) Base – The middle region of the transistor is known as base. Base region is very lightly doped and is very thin as compared to emitter or collector region so that it may pass most of the injected charge carriers to the collector.

(iii) Collector – It is a region situated in the side opposite to the emitter. The main function of the collector is to collect majority charge carriers through the base. The doping of collector is between the heavy doping of the emitter and the light doping of the base.

Q.74. Explain the working principle of p-n-p transistor.

Ans. Fig. 5.60 shows the working of p-n-p transistor with emitter-base junction as forward biased and collector base junction is reverse biased. The forward bias on the emitter-base junction causes the holes in the emitter region to flow towards the base region. The potential barrier at emitter junction is reduced as it is forward bias and therefore the holes cross this junction and penetrate into n-region. This constitutes the emitter current, I_E. The width of the region is very thin and it is lightly doped and hence only 2% and 5% of the holes recombine with the free electrons of base region. They constitute base current, I_B. However, most of the holes do not combine with the electrons in the base region. It is due to the fact that base width is made extremely small and holes do not get sufficient electrons for recombination. Thus most of the holes diffuse to the collector region and constitute collector current, I_C.

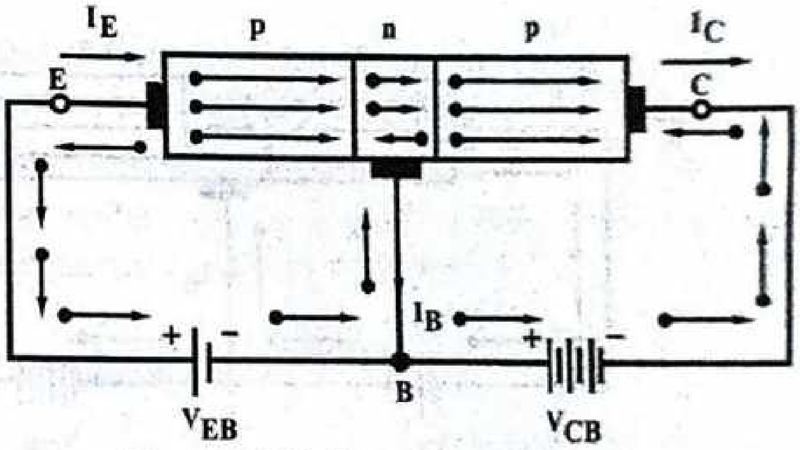


Fig. 5.60 Working of p-n-p Transistor

As each hole reaches the collector electrode, an electron is emitted from the negative terminal of battery and nutralizes the hole. Now, a covalent bond near the emitter electrode breaks down. The liberated electron enters the positive terminal of battery V_{EB} while the hole immediately moves towards the emitter junction. This process repeats again and again. Here, some points should be remembered –

(i) The current conduction within p-n-p transistor takes place by hole conduction from emitter to collector i.e., holes are the majority carriers in a p-n-p transistor.

(ii) The collector current is slightly less as compared to the emitter current.

(iii) The collector current is a function of emitter current i.e., a corresponding change in collector current is observed with the increase or decrease in the emitter current.

As the width of the base region is very small, so practically the electron current may be neglected. Hence in the working of p-n-p transistor only the hole current plays the important role.

Q.75. Draw the schematic diagram of the n-p-n transistor and explain its working. ***(R.G.P.V., June 2008, Sept. 2009)***

Ans. Fig. 5.61 shows the operation of n-p-n transistor with the emitter-base junction forward biased and collector-base junction reverse biased. The emitter-base junction is forward biased only when V_{EB} is greater than barrier potential which is 0.7V for Silicon and 0.3V for Germanium transistors. The forward bias on the emitter-base junction causes the free electrons in the n-type emitter to flow towards the base region. This makes the emitter current, I_E. It may be noted that the direction of conventional current, I_C is opposite to flow of electrons. Therefore electrons, after reaching the base region tend to combine with the holes. When these free electrons combine with the holes in the base, they constitute base current, I_B. However, most of the free electrons do not combine with the holes in the base, because the base width is made extremely small and electrons do not get sufficient holes for recombination. Hence most of the electrons will diffuse to the collector region and constitute collector current, I_C.

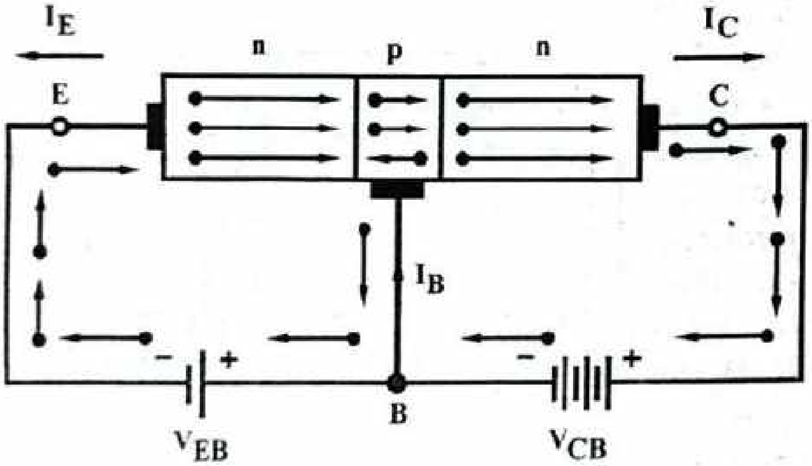


Fig. 5.61 Operation of n-p-n Transistor

For every electron flowing out the collector and entering the positive terminal of battery V_{CB}, an electron from the negative emitter battery terminal enters the emitter region. In this way electron conduc-tion takes place continuously so long the two junctions are properly biased. So, in n-p-n transistor the current conduction is carried out by electrons.

Q.76. Discuss the working principle of BJT. ***(R.G.P.V., Nov. 2018)***

Or

Explain the bipolar junction transistor (BJT) and their working. ***[R.G.P.V., Nov. 2018(O)]***

Ans. Refer the ans. of Q.73, Q.74 and Q.75.

INTRODUCTION TO CC, CB & CE TRANSISTOR CONFIGURATIONS, DIFFERENT CONFIGURATIONS AND MODES OF OPERATION OF BJT

Q.77. Define common-base D.C. current gain α.

Ans. It is defined as the ratio of collector current (I_C) to emitter current (I_E) and is usually designated by α, α_{DC} or h_{FB}. It is also referred to as large-signal common-base D.C. current gain. Mathematically,

$$\alpha = \frac{I_C}{I_E}$$

We know that collector current in a transistor is always less than the emitter current. Therefore current-gain of a transistor in common-base configuration is always less than unity.

Q.78. Define common-emitter D.C. current gain β.

Ans. It is defined as the ratio of collector current (I_C) to base current (I_B) and is designated by β, β_{DC} or h_{FE}. Mathematically, the common-emitter D.C. current gain,

$$\beta = \frac{I_C}{I_B}$$

Now, we know that collector current of a transistor is much larger than the base current. Therefore, the value of β is much greater than unity.

Q.79. Establish the relationship between α and β.

Ans. We know that emitter current (I_E) of a transistor is the sum of its base current (I_B) and collector current (I_C). Therefore,

$$I_E = I_B + I_C$$

Dividing the above equation on both sides by I_C,

$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$$

Since, $I_C/I_E = \alpha$ and $I_C/I_B = \beta$. Therefore,

$$\frac{1}{\alpha} = \frac{1}{\beta} + 1 = \frac{1+\beta}{\beta}$$

$$\alpha = \frac{\beta}{\beta+1} \text{ or } \beta = \frac{\alpha}{1-\alpha}$$

Q.80. Explain the α (small signal current gain) with reference to BJT.

Ans. The small signal current gain α is defined as the ratio of small change in collector current (ΔI_C) to a small change in emitter current (ΔI_E) for a constant collector-to-base voltage (V_{CB}). It is designated by α_{AC} or h_{FB}. It is

also called small-signal common base A.C. current gain. Mathematically,

$$\alpha_{AC} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB} = \text{Constant}}$$

Q.81. Explain the reverse saturation current I_{CBO} with reference to BJT.

Ans. The collector current in a physical transistor when the emitter current is zero designated by the symbol I_{CBO}. Two factors cooperate to make $|I_{CBO}|$ larger than $|I_{CO}|$. First there exists a leakage current which flows, not through the junction but around it and across the surfaces. The leakage current is proportional to the voltage across the junction. The second reason why $|I_{CBO}|$ exceeds $|I_{CO}|$ is that new carriers may be generated by collision in the collector-junction transition region, leading to avalanche multiplication of current and eventual breakdown. But even before breakdown is approached, this multiplication component of current may attain considerable proportions.

Q.82. Discuss the three configuration of transistor. How do they differ from each other. ***(R.G.P.V., Dec. 2012)***

Or

Draw the circuit of various transistor configurations. List their important features. ***(R.G.P.V., Dec. 2010)***

Ans. The transistors can be connected in the following configurations –

(i) Common-base Configuration – In this configuration, the transistor is connected with the base as a common terminal as shown in fig. 5.62.

The input is applied between the emitter and base terminals. The output is taken between the collector and base terminals. This type of configuration is used to explain the operation of NPN and PNP transistors.

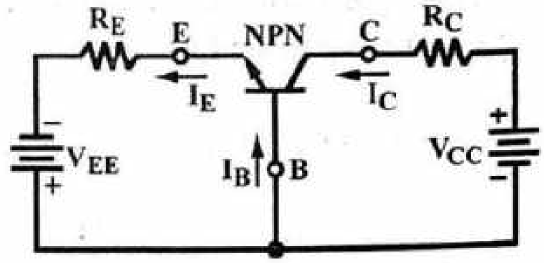


Fig. 5.62

(ii) Common-emitter (CE) Configuration – In this configuration, the transistor is connected with the emitter as a common terminal as shown in fig. 5.63.

The input is applied between the base and emitter terminals. The output is taken between collector and emitter terminals. This is one of the most commonly used configuration of a transistor.

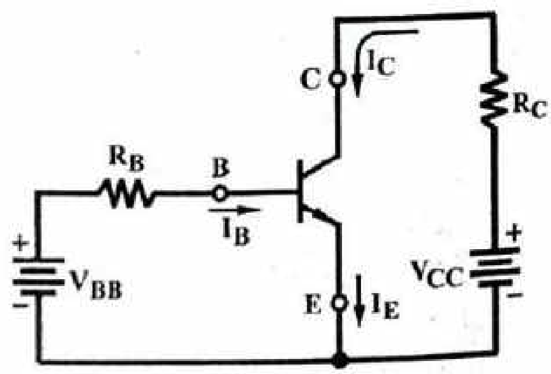


Fig. 5.63

(iii) Common-collector (CC) Configuration – In this configuration, the transistor is connected with collector as a common terminal as shown in fig. 5.64. The input is applied between the base and collector terminals. The output is taken between emitter and collector terminals.

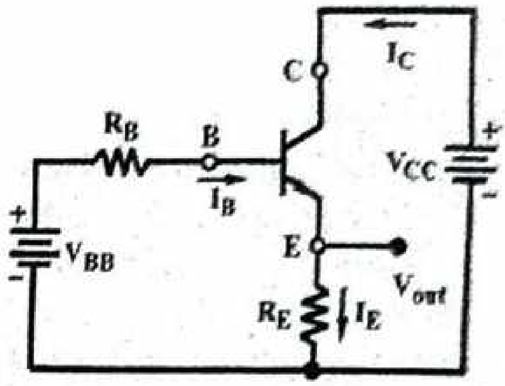


Fig. 5.64

Comparison of the Three Configurations of the BJT –

S.No.	Property	Common Emitter	Common Base	Common Collector
(i)	Transistor Resistance	Output resistance of the transistor is of the order of 50 kΩ and input resistance is 1 to 2 kΩ.	Output resistance of the transistor is very high, of the order of 1 to 2 MΩ, Input resistance is very low of the order of 20 to 50Ω.	Output resistance of the transistor is very low, of the order of 100 to 1000 ohms. The input resistance is very high of the order of 150 kΩ to 600 kΩ.
(ii)	Current gain	Large current gain 20 to 200 (β)	Approximate no current gain, 0.85 to 0.995 (α)	Current gain is high 20 to 200 (1 + β)
(iii)	Voltage gain	Very high	High	Voltage gain is always less than unity.
(iv)	Power gain	Highest power gain	Moderate	Power gain is less than other type of circuits.
(v)	Phase of input and output signal	Input and output signals 180° apart	No phase reversal	No phase reversal.

Q.83. Compare the CE, CB and CC configuration of BJT on the basis of –
(i) Input resistance (ii) Output resistance
(iii) Voltage gain (iv) Current gain.

(R.G.P.V., June 2012)

Ans. Refer the ans. of Q.82.

Q.84. Which transistor configuration CC, CB and CE is suitable for amplifier and why ? ***(R.G.P.V., June 2013)***

Or

Which is the best transistor configuration for amplifiers and why ?
(R.G.P.V., June 2014)

Ans. The common-emitter configuration is widely used amongst three transistor configurations. The main reasons for the wide-spread use of the circuit arrangement are as follows –

(i) The CE configuration is the only configuration which gives both voltage gain as well as current gain greater than unity in case of CC configuration voltage gain is less than unity and in case of CB configuration current gain is less than unity.

The power gain is a product of voltage gain and current gain. The CE configuration gives current gain nearly equal to current gain provided CC configuration (current gain is maximum in CC) and voltage gain nearly equal to voltage gain provided by CB configuration (voltage gain is maximum in CB). Hence the power gain of the CE amplifier is much greater than the power gain given by the other two configurations (voltage gain in CC and current gain in CB are less than unity).

(ii) In a common emitter circuit, the ratio of output resistance to input resistance is small, may range from 10 Ω to 100 Ω. Although in other connections, the ratio of output resistance to input resistance is very large and hence coupling becomes highly inefficient due to large mismatch of resistance.

Q.85. Draw a schematic diagram of a transistor indicating the different currents. Arrive at the relationship among them. (R.G.P.V., Jan./Feb. 2008)

Ans. The three primary currents which flow across the forward biased emitter junction and reverse biased collector junction are I_e, I_b and I_c. Fig. 5.65 shows the directions of flow of these currents for a p-n-p transistor connected in a common-base configuration. It is obvious that,

$$I_e = I_c + I_b$$

By normal convention, current flowing into a transistor is taken as positive whereas current flowing out of it, is taken as negative. The ratio of the collector current to the emitter current is called D.C. alpha (α_{DC}) of a transistor

$$\alpha_{DC} = -\frac{I_c}{I_e} \text{ or Simply } \alpha = \frac{I_c}{I_e}$$

The negative sign shows that I_c flows out of the transistor. Now we have,

$$I_c = \alpha I_e$$

and

$$I_b = I_e - I_c$$

$$I_b = I_e - \alpha I_e$$

$$I_b = I_e(1 - \alpha)$$

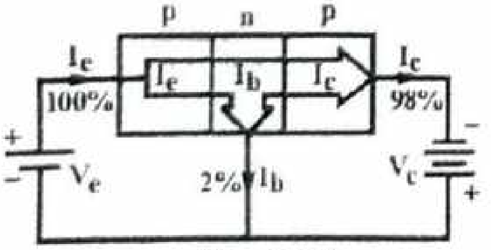


Fig. 5.65

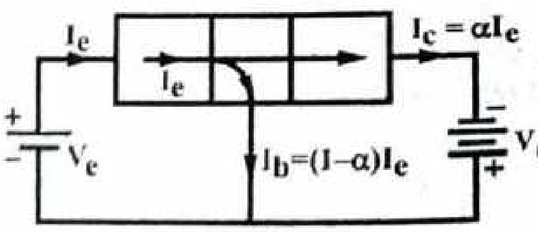


Fig. 5.66

So considering the current due to majority carriers, the emitter current splits into two parts –

(i) $I_e(1 - \alpha)$ which becomes base current I_b in the external circuit.

(ii) αI_e which becomes collector current I_c in the external circuit.

These currents are shown in fig. 5.66.

In a p-n-p transistor, although the collector-base junction is reverse biased for majority charge carriers (holes) but it is forward biased for thermally-generated minority charge carriers (electrons). So a current flows in the same direction of I_c due to the minority carriers (electrons). This is called a leakage current and is denoted by I_{cbo} or I_{co}. This current flows even when emitter is disconnected from the D.C. supply source. Here cbo stands for current from collector to base with emitter open. The current is extremely temperature dependent because it is made up of thermally generated minority carriers. Similarly current I_{ne} flows in the emitter base circuit as shown in fig. 5.67. If we take into account the leakage currents distribution in a common-base circuit becomes as shown in fig. 5.68.

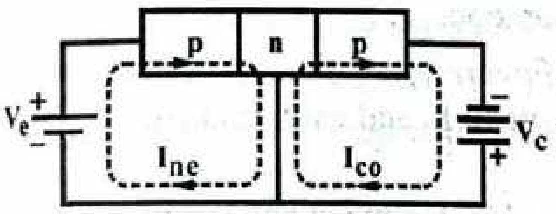


Fig. 5.67

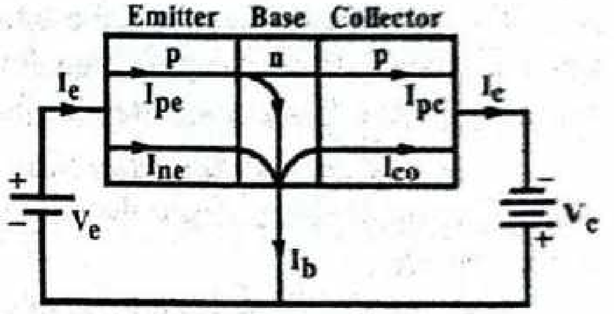


Fig. 5.68

Here, the emitter current I_e consists of hole current I_{pe} (holes crossing from emitter into base) and electron current I_{ne} (electrons crossing from base into the emitter). The collector current I_c consists of I_{pc} (holes crossing from base to collector) and temperature dependent current I_{co} due to minority carriers (electrons crossing from collector to base). Thus,

$$I_c = I_{pc} + I_{co}$$

$$I_c = \underbrace{\alpha I_e}_{\text{Majority}} + \underbrace{I_{co}}_{\text{Minority}}$$

The base current I_b consists of $(I_{pe} - I_{pc})$, I_{ne} and I_{co}.

Q.86. What is a transistor ? Draw electrical symbol of transistor. Also describe the currents in a typical transistor. ***(R.G.P.V., May 2018)***

Ans. Refer the ans. of Q.73 and Q.85.

Q.87. Explain the working of bipolar junction transistors in CC configuration. ***(R.G.P.V., March/April 2010)***

Ans. In common-collector configuration input signal is applied between base and collector circuit and output is taken out from emitter-collector circuit.

Here, collector terminal of the transistor is common to both input and output circuits and hence the name common-collector configuration. Fig. 5.69 shows common-collector p-n-p transistor circuit. Basically this circuit is the same as the circuit of common emitter configuration, with the exception that the load resistor is in the emitter lead rather than in the collector circuit. When the base current is I_{CO}, the emitter current will be zero and no current will flow in the load. As the transistor is brought out of this reverse biased condition by increasing the magnitude of the base current, the transistor will pass through the active region and eventually reach saturation. In this condition all the supply voltage, except for a very small drop across the transistor will appear across the load.

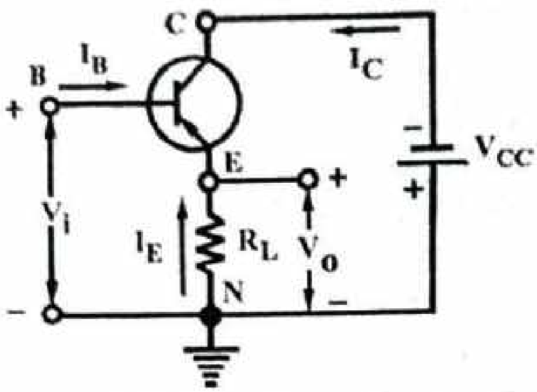


Fig. 5.69 Transistor Common-collector Configuration

If we continue to specify the operation of the circuit in terms of the currents which flow, the operation for the common-collector is much the same as for the common-emitter configuration.

(i) Current Amplification Factor (γ) – In common-collector configuration, input current is the base current I_B and emitter current I_E is the output current.

The ratio of change in emitter current (ΔI_E) to the change in base current (ΔI_B) is known as current amplification factor in common-collector (CC) configuration

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

However, its voltage gain is always less than 1.

Calculate the Relation between α and γ – The current amplification factor is given by

$$\gamma = \frac{\Delta I_E}{\Delta I_B} \qquad ...(i)$$

and

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \qquad ...(ii)$$

Now,
$$I_E = I_B + I_C$$

or
$$\Delta I_E = \Delta I_B + \Delta I_C$$

or
$$\Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the value of ΔI_B in equation (i), we get

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C} \qquad ...(iii)$$

Dividing the numerator and denominator of the R.H.S. of equation (iii) by ΔI_E, we have

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{1}{1-\alpha} \qquad \left(\because \alpha = \frac{\Delta I_C}{\Delta I_E}\right)$$

(ii) Expression for Collector Current – For common-collector configuration, we have

$$I_C = \alpha I_E + I_{CBO}$$

also

$$I_E = I_B + I_C = I_B + (\alpha I_E + I_{CBO})$$

$$I_E (1 - \alpha) = I_B + I_{CBO}$$

or

$$I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

$$I_E = (\beta + 1)\, I_B + (\beta + 1)\, I_{CBO}$$

The common collector circuit has very high input resistance and very low output resistance. This is the region, the voltage gain provided by common collector circuit is always less than 1 (or unity). However, due to relatively high input resistance and low output resistance, this circuit is primarily used for impedance matching.

Q.88. Explain the input and output characteristics of a transistor in CB configuration.

Ans. The output characteristics of a common-base p-n-p transistor is shown in fig. 5.70. It is the plot along the y-axis and to the right that polarity of V_{CB} which reverse biases the collector junction even if this polarity is negative. If emitter current is equal to zero, the collector current is $I_C = I_{CO}$.

For other values of emitter current, the output-diode reverse current is augmented by the fraction of the input-diode forward current which reaches the collector. Note that I_C and I_{CO} are negative for a p-n-p transistor and positive for n-p-n transistor.

This characteristic may be used to find α of the transistor in the form

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \qquad ...(i)$$

Although collector current (I_C) is practically independent of collector to base voltage (V_{CB}) over the working range of the transistor. This is represented as

$$I_C = \phi_2 (V_{CB}, I_E) \qquad ...(ii)$$

The relation of equation (ii) is shown in fig. 5.70 for a typical p-n-p Germanium transistor and is a plot of collector current (I_C) versus collector to base voltage (V_{CB}) with emitter current (I_E) as a parameter.

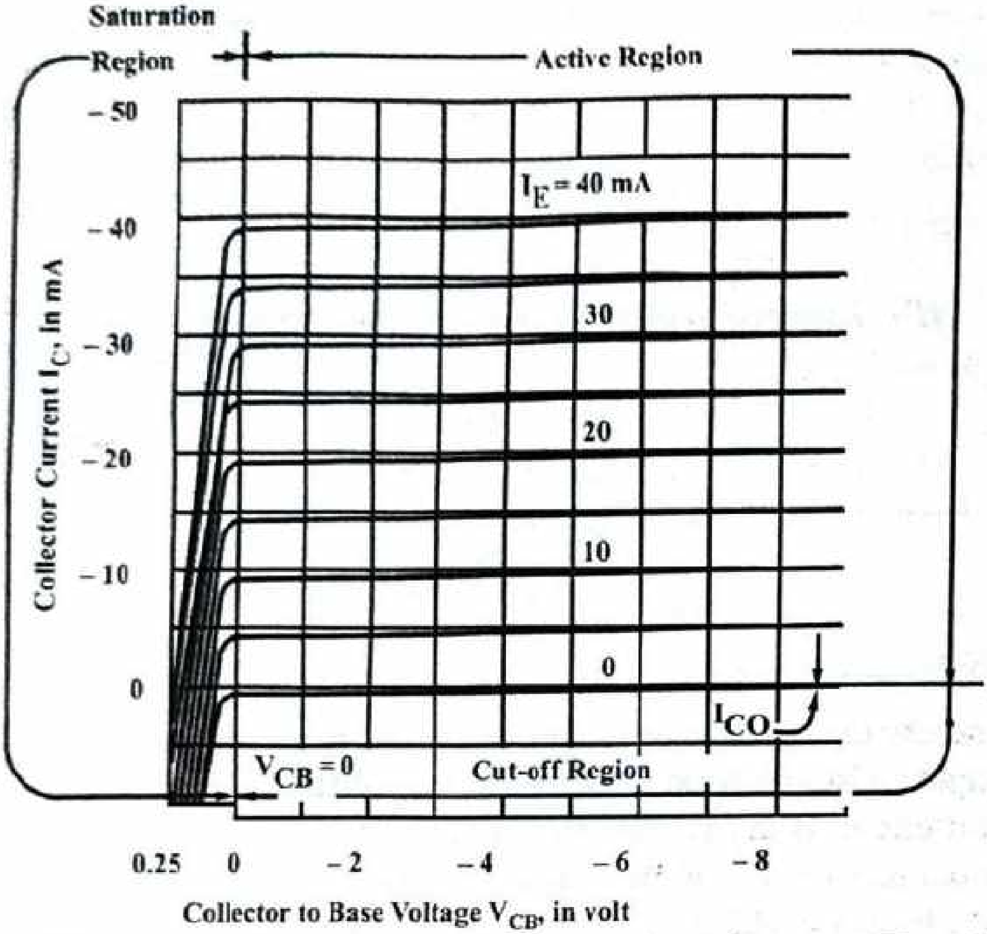


Fig. 5.70 Common-base Output Characteristics of a p-n-p Transistor

*(i) **Active Region*** – The active region of the characteristic is one in which the emitter junction is forward biased and collector junction is reverse biased. When the emitter current (I_E) is zero, the transistor behaves as a junction diode constituted by base-collector region. In this case, the collector current is small and is equal to the I_{CO}. Its magnitude is of the order of microamperes for Germanium and nanoamperes for Silicon. The I_{CO} is negative for a p-n-p transistor and positive for n-p-n transistor. Consider that a forward emitter current I_E flows in the emitter circuit. Then a fraction $-\alpha I_E$ of this current will reach the collector. The slight positive slope of the output characteristics gives rise to a finite output conduction instead of zero output conductance.

*(ii) **Saturation Region*** – The saturation region is characterized by both the emitter and collector junctions being forward biased. This region is towards to left of the ordinate $V_{CB} = 0$ and above $I_E = 0$. Consider that V_{CB} is slightly positive. Now the forward bias of collector accounts for the large change in collector current with small changes in collector voltage. For a forward bias, the collector current I_C increases exponentially with voltage.

*(iii) **Cut-off Region*** – In cut-off region, the emitter and collector junctions are reversed biased. Such condition exists in the region below and to the right of $I_E = 0$ characteristic. This characteristic is not coincident with the voltage axis, though the separation is difficult to show because I_{CO} is only a few nanoamperes and microamperes.

Input Characteristics – A plot of emitter to base voltage (V_{EB}) versus emitter current (I_E) with collector to base voltage (V_{CB}) as a parameter, is shown in fig. 5.71. The curves of fig. 5.71 is also known as input characteristics. The feature of input characteristics is that there exists a cut-in, offset or threshold voltage below which the emitter current is very small.

The shape of the input characteristics can be understood if we consider the fact that an increase in magnitude of collector voltage will be, by the Early effect, cause the emitter current to increase, with V_{EB} held constant. Thus the curves shift downward as $|V_{CB}|$ increases, as shown in input characteristics.

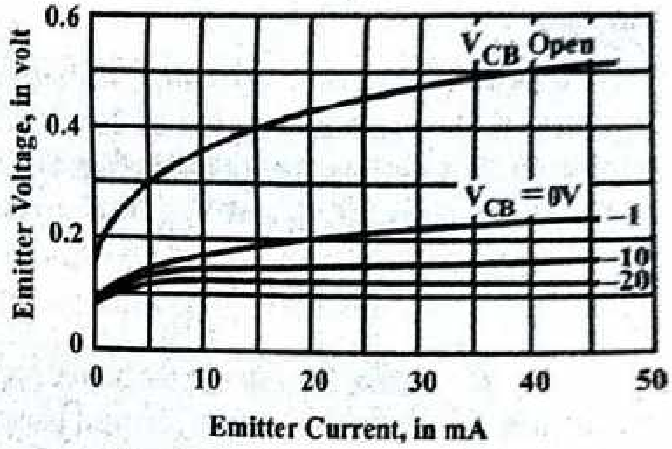


Fig. 5.71 Common-base Input Characteristics of a p-n-p Transistor

Q.89. Draw the common-emitter output characteristics of a transistor and show the cut-off, active and saturation regions on it.

Or

Explain the operation of BJT under following mode –
(i) Cut-off mode (ii) Active mode (iii) Saturation mode.
(R.G.P.V., June 2012)

Ans. The output characteristics for a common-emitter p-n-p transistor are the curves between collector current (I_C) and collector-emitter voltage (V_{CE}) for various values of the base current (I_B). In the active region, the

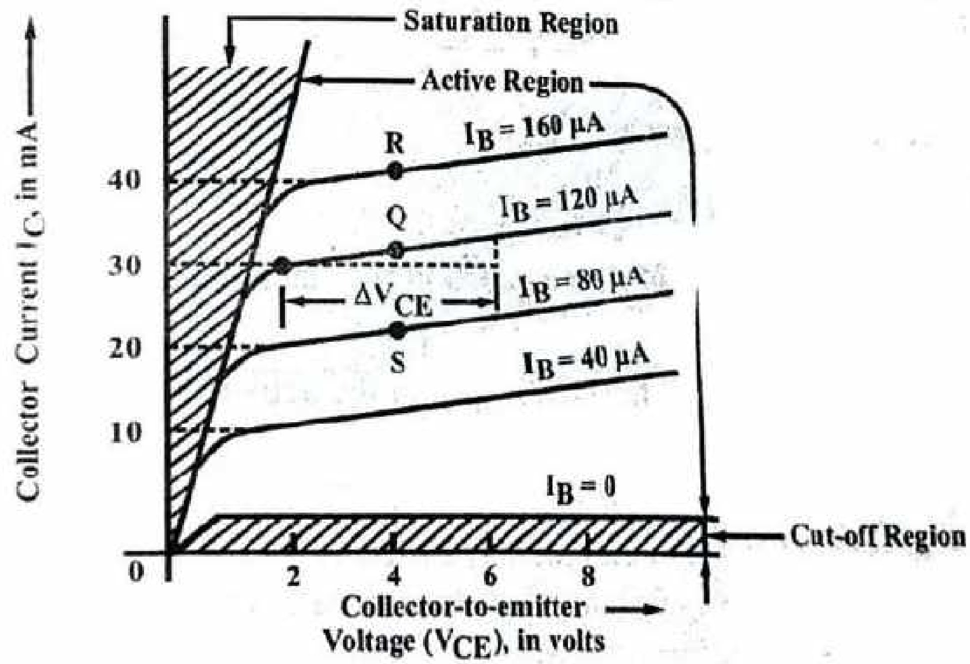


Fig. 5.72 Output Characteristics of a Common-emitter p-n-p Transistor

collector junction is reverse-biased and emitter junction is forward-biased. In the output characteristics the active region is the area to the right of the ordinate the collector to emitter voltage is few tenths of a volt and above $I_B = 0$. In this region the transistor output current responds most sensitively to an input signal.

The output characteristics for a common-emitter transistor is shown in fig. 5.72.

When V_{CE} has very low value, the transistor is said to be saturated and it operates in the saturation region of the characteristic. Here, change in I_B does not produce a corresponding change in I_C. This characteristic can be used to obtain the value of β, I_B and V_{CE}. It is given by

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{...(i)}$$

(i) ***Active Region*** – In the active region the collector junction is reverse biased and the emitter junction is forward biased. In input characteristic the active region is the area to the right of the ordinate V_{CE} is equal to a few tenths of the volt and above $I_B = 0$. In this region the transistor output current responds most sensitively to an input signal. If the transistor is to be used as an amplifying device without appreciable distortion, it must be restricted to operate in this region.

Applying Kirchhoff's current law (KCL) to the transistor common-emitter circuit, then we find the expression for base current as

$$I_B = I_E - I_C \quad \text{...(ii)}$$

The emitter is forward biased, so we have

$$I_C = I_{CO} + \alpha I_E \quad \text{...(iii)}$$

Substitute the value of I_E from equation (ii) into equation (iii), we get

$$I_C = I_{CO} + \alpha(I_C + I_B)$$

$$I_C = \frac{I_{CO}}{1-\alpha} + \frac{\alpha I_B}{1-\alpha} \quad \text{...(iv)}$$

We define β in the form as

$$\beta = \frac{\alpha}{1-\alpha}$$

Substituting this value of β into equation (iv), then we get

$$I_C = (1+\beta)\, I_{CO} + \beta I_B$$

We note that $I_B >> I_{CO}$, hence $I_C \approx \beta I_B$ in the active region.

(ii) ***Cut-off Region*** – The cut-off region in input characteristic occurs at the intersection of the load line with the current $I_B = 0$. However, we find that appreciable collector current may exist under these conditions. From equations (ii) and (iii), if $I_B = 0$ then $I_E = I_C$ and we have

$$I_C = I_E = \frac{I_{CO}}{1-\alpha} = I_{CEO}$$

where, I_{CEO} is the actual collector current with collector junction reverse biased and base open circuited. The cut-off means that $I_E = 0$, $I_C = I_{CO}$, $I_B = -I_C = -I_{CO}$ and V_{BE} is a reverse voltage.

(iii) Saturation Region – In the saturation region, the collector junction as well as the emitter junction is forward biased by at least the cut-in voltage. Since the voltage V_{BE} (or V_{BC}) across a forward biased junction has a magnitude of only a few tenths of a volt, the $V_{CE} = V_{BE} - V_{BC}$ is also only a few tenths of a volt at saturation.

Q.90. Draw and explain in brief the input characteristics of common-emitter transistor.

Ans. Input characteristics for a common-emitter p-n-p transistor are the curves between base current (I_B) and base-emitter voltage (V_{BE}) for various values of collector-to-emitter voltage (V_{CE}). If base-emitter voltage becomes zero then base current will be zero, since under these conditions both emitter and collector junctions will be short-circuited.

In general, increasing the collector-emitter voltage with constant base-emitter voltage causes a decrease in basewidth and results in a decreasing recombination base current. The typical common-emitter input characteristics is shown in fig. 5.73.

We observe that with the collector shorted to the emitter and the emitter forward biased, the input characteristic is essentially that of a forward biased diode. If the base emitter voltage (V_{BE}) becomes zero, then base current (I_B)will be zero since under these conditions both emitter and collector junctions will be short circuited.

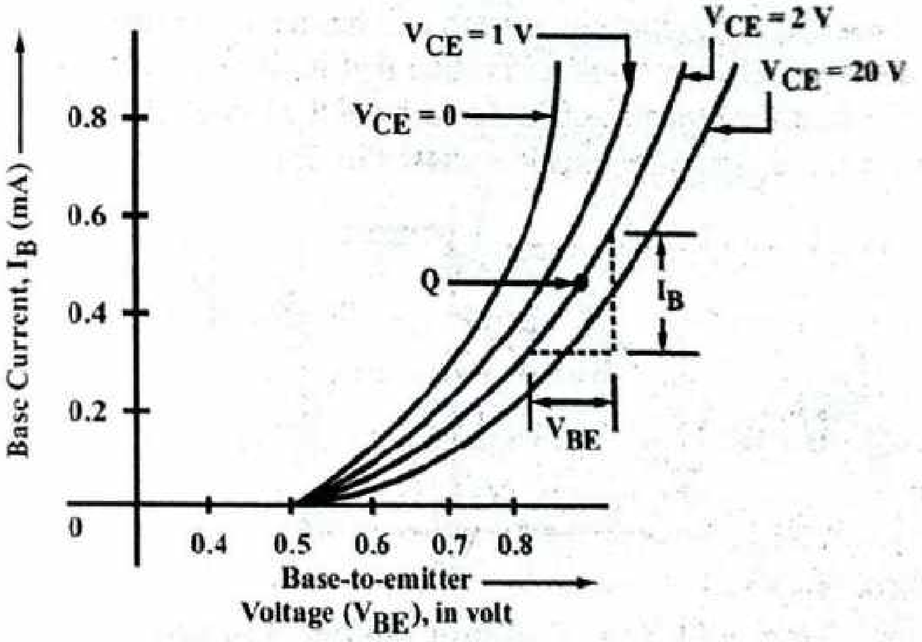


Fig. 5.73 Common-emitter Input Characteristics of a p-n-p Transistor

Q.91. Draw input/output characteristics of a transistor in CE configuration.
(R.G.P.V., June 2010, 2011, 2013)

Ans. Refer the ans. of Q.89 and Q.90.

Q.92. Explain the working of bipolar junction transistor in common-emitter configuration. ***(R.G.P.V., Dec. 2011)***

Or

Explain the working of transistor when it is operated in CE mode. ***(R.G.P.V., Dec. 2013)***

Or

Draw the connection diagram and explain the use and working of CE transistor configuration. ***(R.G.P.V., Dec. 2014)***

Ans. Refer the ans. of Q.82 (ii).

In this circuit arrangement, the base current I_B flows in the input circuit and collector current I_C flows in the output circuit. In this arrangement, current gain between the input and output sides is obtained. Since the input resistance is again less than the output resistance there will be high voltage and power gains like those in equivalent vacuum tube circuits. Common emitter (CE) is commonly used because its current, voltage and power gains are quite high and output to input impedance ratio is moderate.

Also refer the ans. of Q.89 and Q.90.

Q.93. Explain how transistor acts as an amplifier. ***(R.G.P.V., March/April 2009, 2010)***

Ans. Fig. 5.74 shows a basic circuit of an amplifier, In this circuit an NPN transistor is used in the common emitter configuration. Therefore the basic circuit is known as a basic common emitter amplifier. Here V_{BB} supply forward biases the emitter base junction and V_{CC} supply reverse biases the collector base junction. This biases the transistor to operate in the active region V_S is a sinusoidal A.C. input signal source. It has a source resistance R_S. The magnitude of signal source voltage is such that it always forward-biased the emitter-base junction regardless of the polarity of the signal. A brief description of the operation of amplifier circuit is shown in fig. 5.74.

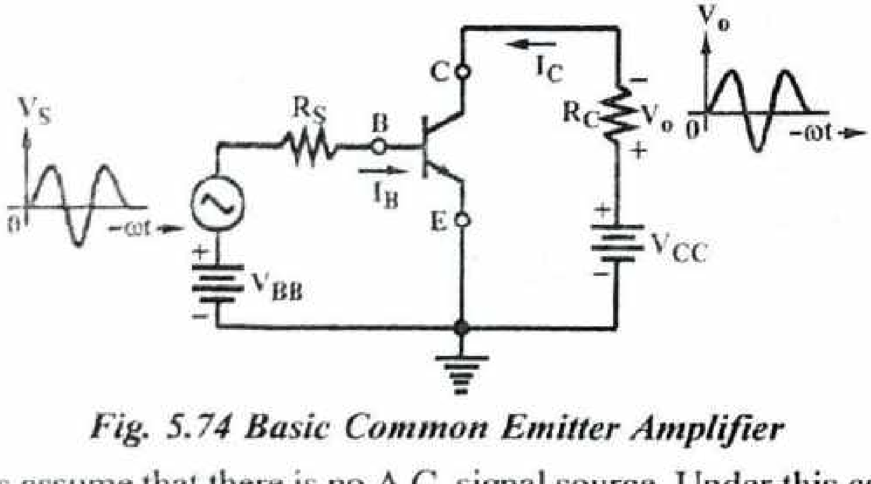


Fig. 5.74 Basic Common Emitter Amplifier

Let us assume that there is no A.C. signal source. Under this condition, a D.C. collector current (I_C) flows through the collector load (R_C). This is called zero signal current or quiescent operating current. Now let an A.C. ıal be applied between the emitter-base junction. During the positive half-

cycle of the input signal, the forward-bias across the emitter-base junction is increased. As a result, more electrons are injected into the base to reach the collector which increase the collector current. The increased collector current produces greater voltage drop across the resistance R_C. During the negative half-cycle, the forward-bias across the emitter-base junction is decreased. Due to this, the collector-current decreases. The decreased collector current produces smaller voltage drop across resistance R_C.

It is evident from the above discussion, that a small A.C. signal at the input produces a large A.C. signal at the output or load resistance. Thus the transistor act as an amplifier.

Q.94. Explain how a BJT can be used as (i) An amplifier (ii) switch.
(R.G.P.V., Dec. 2011)

Ans. (i) Transistor as an Amplifier – Refer the ans of Q.93.

(ii) Transistor as an Switch – The switching action of a transistor can be explained with the help of its output characteristics. Fig. 5.75 (a) shows the transistor as a switch with a step input voltage and fig. 5.75 (b) shows the load line on characteristic curves. The transistor is used in CE configuration and the load line is drawn for load R_C and collector supply V_{CC}. In this circuit, by reverse biasing the base-emitter junction, the leakage current is reduced.

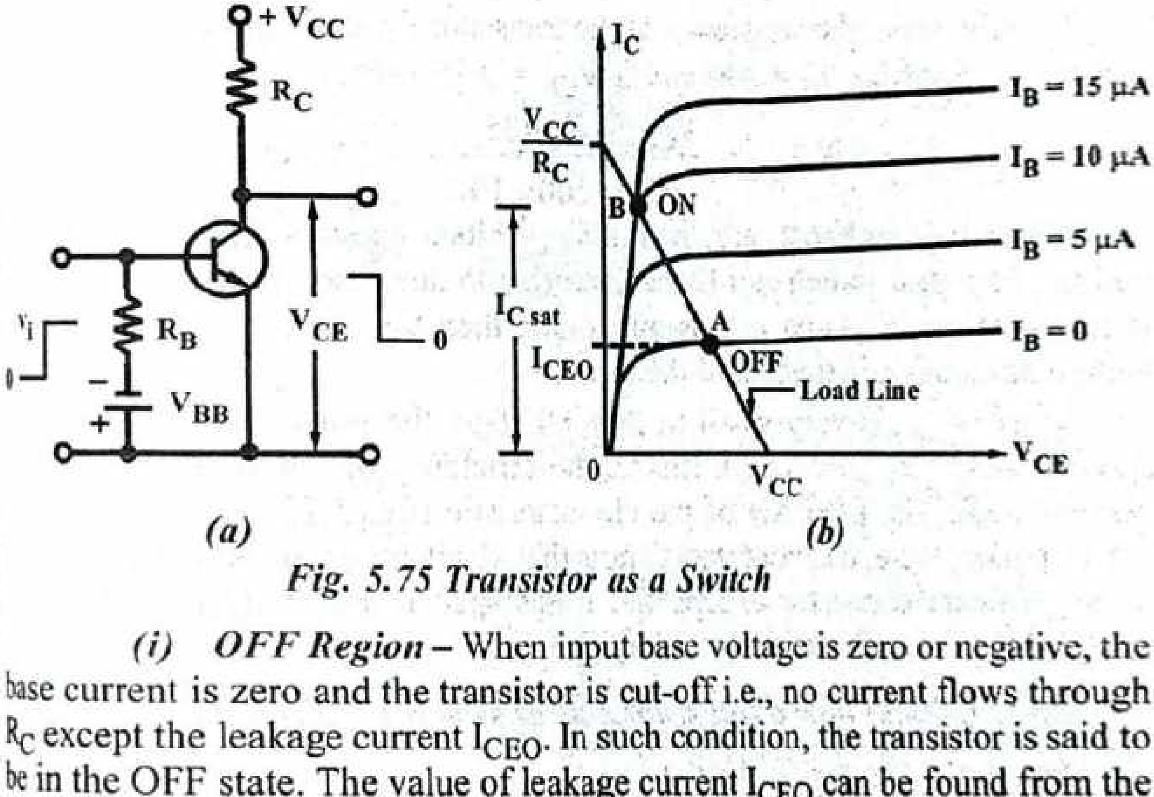


Fig. 5.75 Transistor as a Switch

(i) OFF Region – When input base voltage is zero or negative, the base current is zero and the transistor is cut-off i.e., no current flows through R_C except the leakage current I_{CEO}. In such condition, the transistor is said to be in the OFF state. The value of leakage current I_{CEO} can be found from the characteristics provided we know the value of V_{CE}. In this state, the voltage between collector and emitter is maximum and is equal to V_{CC}. This is due to the fact that there is negligible voltage drop across R_C when $I_C = 0$.

Now, suppose that V_{CE} is 12 V and I_{CEO} is 0.3 mA, then the resistance offered by the transistor in the OFF state is calculated as –

$$R_{OFF} = \frac{V_{CE}}{I_{CEO}} = \frac{12}{0.3 \times 10^{-3}} = 40\ k\Omega$$

When the leakage current 0.3 mA is objectionable, then it is decreased by reverse biasing the base-emitter junction. This decreases the leakage current down to cut-off current. For a typical switching silicon transistor, under reverse bias condition, the cut-off current I_{CO} is nearly 30 mA.

In this case,

$$R_{OFF} = \frac{V_{CE}}{I_{CO}} = \frac{12}{30 \times 10^{-3}} = 400\ \Omega$$

Definitely, the transistor switch is off with this resistance.

(ii) ON or Saturation Region – If the input voltage is made so much positive that saturation collector current flows, the transistor is said to be in ON state. The value of base current necessary to do this can be obtained from the load line. It is important to note that more current than the minimum base current to just cause saturation is used to switch a transistor. In this state,the saturation collector current is given by the relation –

$$I_{C\ sat} = \frac{V_{CC} - V_{knee}}{R_C}$$

In 'ON' state, the resistance of the transistor depends upon the collector current I_C. Suppose, $I_C = 200$ mA at $V_{CE} = 0.35$ V, then –

$$R_{ON} = \frac{V_{CE}}{I_C} = \frac{0.35}{200 \times 10^{-3}} = 1.75\ \Omega$$

When V_{CE} is almost zero, the full V_{CC} voltage appears across the load R_C and the transistor switch acts like an inverter. In this case, if v_i zero, then V_{CE} is maximum at V_{CC} and if v_i is maximum, then V_{CE} is minimum near 0 V. Hence, the output is inverse of the input.

Since V_{knee} is very small in the ON state, the power loss is very low (power loss = $V_{knee} \times I_{C\ sat}$). Hence, the efficiency of a transistor as in ON state is high. The path AB of the characteristic [fig. 5.75 (b)] is called the active region. Here, it is important to note that a switching transistor is fabricated as an ordinary transistor except that it has special designing to reduce the switch-off time and saturation voltage.

Q.95. Explain how a transistor acts as switch ? (R.G.P.V., May 2019)

Ans. Refer the ans. of Q.94 (ii).

Q.96. How BJT can be used as –

(i) Switch (ii) Inverter. (R.G.P.V., June 2013)

Or

Explain in short application of transistor. (R.G.P.V., Dec. 2013)

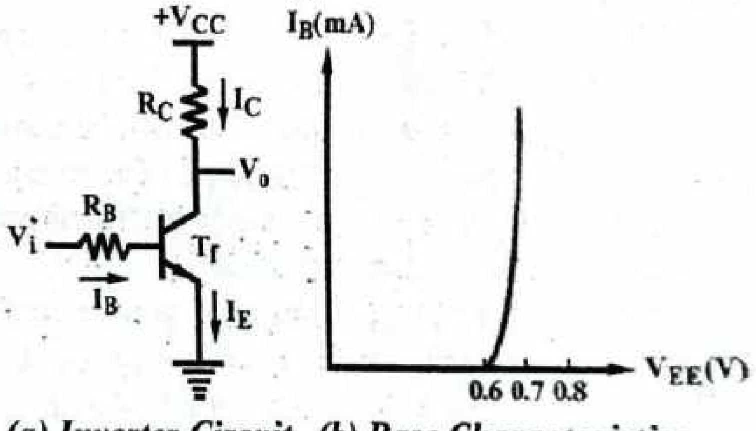
Ans. (i) Switch – Refer the ans. of Q.94 (ii).

(ii) Inverter – Fig. 5.76 (a) is a simple inverter circuit which is consists of two resistors R_B and R_C and a transistor. The current I_B flows through the resistor R_B and the baseof the transistor. This is called base current. the current I_C flows through the resistor R_C and the collector of the transistor. This current is called collector current. The emitter terminal is grounded and the current flows through emitter $I_E = I_C + I_B$. The V_{BE} stands for base to emitter voltage V_{CE} stands for the collector to emitter voltage.

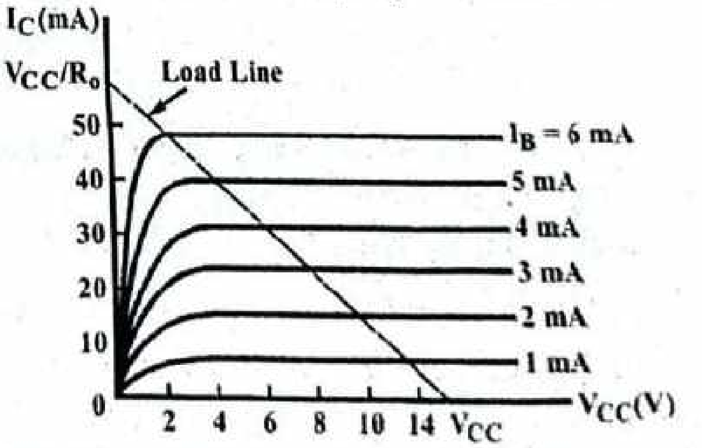
The base emitter characteristic of n-p-n BJT is shown in fig. 5.76 (b). This is the plot of base current variation with respect to V_{BE}. For silicon made transistor, when the base emitter voltage V_{BE} is less than 0.6 V, the transistor is said to be cut-off. Consequently, base current $I_B = 0$ and very small current flows in the collector. Then collector to emitter circuit behaves as an open circuit. When the base-emitter junction is forward biased and is greater than 0.6 V, the transistors begins to conduct and the base current I_B increases rapidly as shown in fig. 5.76 (b) and the voltage across base-emitter junction is about 0.8 V.

Fig. 5.76 (c) shows the collector emitter characteristics with a typical load line. When V_{BE} is less than 0.6 V, the transistor is at cut-off and no base current flows, but negligible current flows in the collector. The collector to emitter circuit behaves like an open circuit. In active region, the collector to emitter voltage V_{CE} can be varied from about 0.8 V to V_{CC}. The collector current in this region is approximately $h_{fe}I_B$, where h_{fe} is the D.C. current gain of the transistor. It should be noted that the maximum collector current does not depend on the I_B, but on the external resistance R_C. Therefore, V_{CE} is always positive and its lowest possible value is 0 V. After assuming $V_{CE} = 0$, the maximum I_C current can be determined from $I_C = V_{CC}/R_C$.

The relationship between collector current and base current $I_C = h_{fe}I_B$ is valid only when the transistor operates at active region. It can be observed that the base current may be increased



(a) Inverter Circuit (b) Base Characteristics of n-p-n Transistor



(c) Collector Characteristics of n-p-n Transistor

Fig. 5.76

to any desirable value, but the collector current is limited by the external resistance R_C. As a consequence, a situation can be reached when $h_{fe}I_B$ is greater than I_C. When this condition arises, the transistor is said to be in saturation region.

Q.97. What is operating points ? ***(R.G.P.V., Dec. 2011)***

Ans. The zero signal values of I_C and V_{CE} are called the operating point as shown in fig. 5.77. It is known as ***operating point*** because the changes of I_C and V_{CE} occur about this point when signal is applied. It is also termed as ***quiescent (silent) point*** or ***Q-point*** because at this point transistor is silent, i.e., no signal is present there.

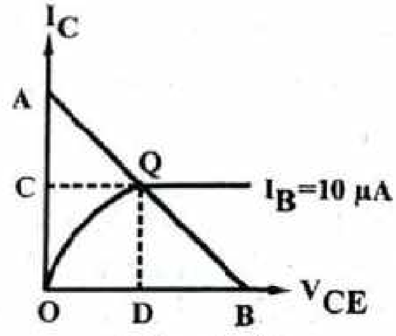


Fig. 5.77

Q.98. Define transistor biasing. ***(R.G.P.V., Dec. 2010, June 2012)***

Or

Discuss D.C. biasing of BJT. ***(R.G.P.V., June 2013)***

Ans. The proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage during the passage of signal is known as transistor biasing.

The purpose of transistor biasing is to keep the base emitter junction properly forward biased and collector base junction properly reverse biased during the application of signal. This can be achieved with a bias battery or associating a circuit with a transistor. The circuit which provide biasing is known as biasing circuit. Transistor biasing is very essential for the proper operation of transistor in any circuit.

When a transistor is not properly biased, it works inefficiently and produces distortion in the output signal. In addition, amount of bias required is important for establishing Q-point which should be stable.

Biasing circuit establishes the operating point in the centre of the active region of the characteristics, so that on applying the input signal the instantaneous operating point does not move either to the saturation region. Biasing stabilizes the collector current against temperature variations.

Q.99. Explain the working of BJT. Discuss D.C. biasing of BJT. ***(R.G.P.V., Dec. 2014)***

Ans. Refer the ans. of Q.74, Q.75 and Q.98.

Q.100. What are the various types of biasing techniques ? Explain.

Ans. In the transistor amplifier circuits, the biasing is done with two power supplies V_{BB} and V_{CC}. The V_{BB} supply is used for biasing of the emitter-base junction and V_{CC} supply for biasing the collector-base junction. However, practically, one power supply is used for biasing both the junctions of a transistor.

Following are the most commonly used techniques for biasing the transistors –

(i) Fixed bias (ii)Collector-to-base bias (iii)Self bias or emitter bias.

(i) Fixed Bias – The operating point Q can be found out by noting the required base current from load line by selecting the base resistance. Now, applying the KVL to the base-emitter circuit of fig. 5.78.

$$V_{CC} = I_B R_B + V_{BE}$$

or

$$I_B R_B = V_{CC} - V_{BE}$$

$\therefore$

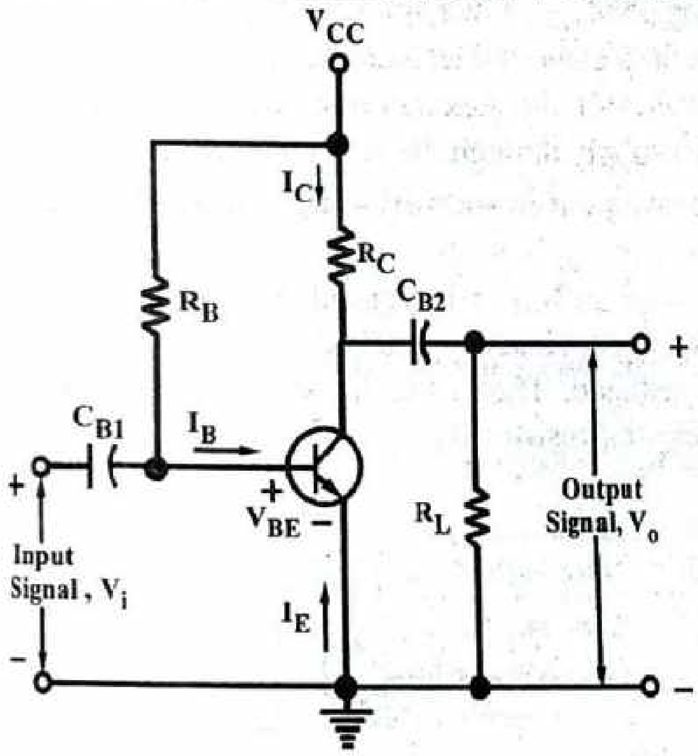
$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad ...(i)$$

But $V_{CC} >> V_{BE}$. Therefore, the equation (i) becomes –

$$I_B \approx \frac{V_{CC}}{R_B} \quad ...(ii)$$

From the equation (ii), V_{CC} is fix and R_B is also fix, hence, the value of I_B is fixed. So, this network is known as the ***fixed-bias circuit.***

The voltage V_{BE} across the forward biased emitter junction is approximately 0.7 V for a 'Si' transistor and 0.2 V for a Ge transistor in the active region.



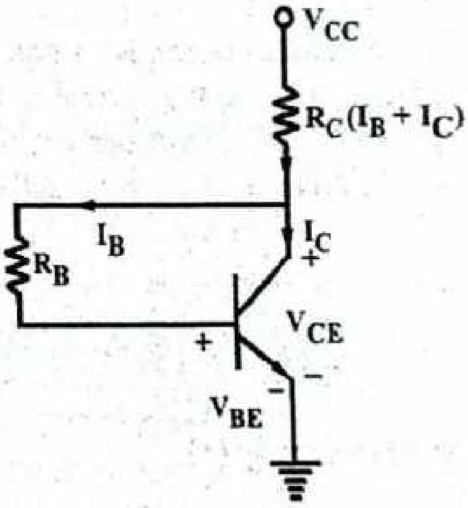


Fig. 5.78 The Fixed-bias Circuit   Fig. 5.79 Collector-to-base Bias Circuit

(ii) Collector-to-base Bias – The circuit of a CE amplifier with collector-to-base bias is shown in fig. 5.79. In this circuit, base resistor R_B is connected between base and collector.

Applying the KVL in the input loop,

$$\begin{aligned} V_{CC} &= R_C (I_B + I_C) + I_B \cdot R_B + V_{BE} \\ &= R_C \cdot I_C + (R_C + R_B) I_B + V_{BE} \end{aligned}$$

or
$$I_B = \frac{(V_{CC} - R_C I_C) - V_{BE}}{R_C + R_B} \quad \ldots(iii)$$

Now, applying KVL in the output loop,

$$V_{CE} = V_{CC} - (I_C + I_B)\, R_C$$
$$\approx V_{CC} - I_C R_C \quad (\text{because } I_C >> I_B) \quad \ldots(iv)$$

The following expression is obtained by combining the equations (iii) and (iv), we get –

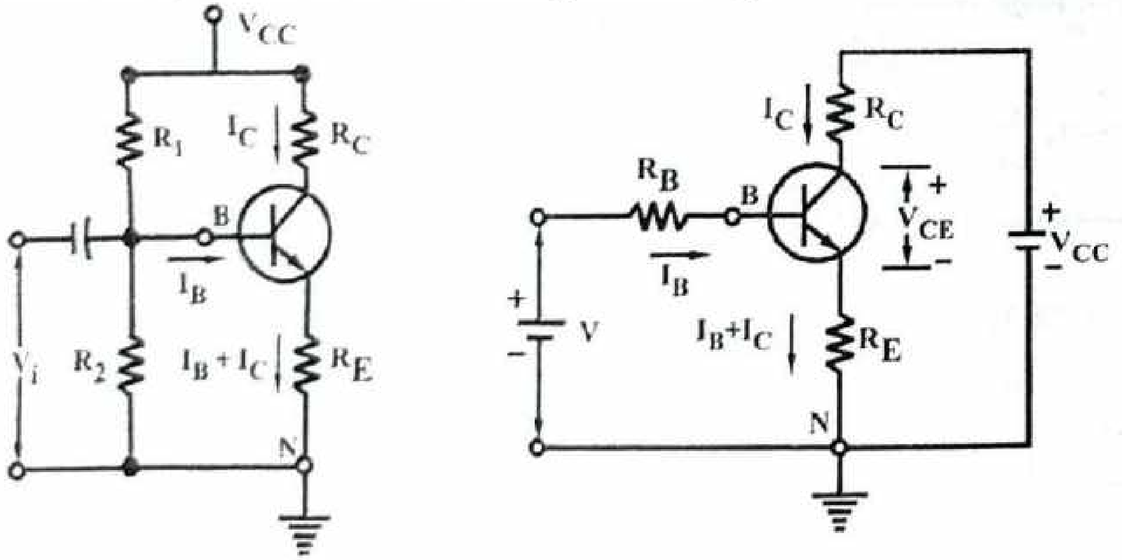
$$I_B = \frac{V_{CE} - V_{BE}}{R_C + R_B} \quad \ldots(v)$$

Now, leakage current I_{CEO} and β increases on increasing temperature. As, I_C increases, there becomes an decrement is V_{CE} equal to $(\beta I_B + I_{CEO})$. Due to this decrement in V_{CE}, I_B reduced. This decrement in I_B decreases the original increase in collector current (because $I_C = \beta I_B + I_{CEO}$). By this mechanism, the collector current is not permitted to rise unduely due to rise in temperature. Hence, the operating point is stabilized by this biasing.

(iii) Voltage-divider Bias (or Self Bias) – A self-biasing configuration is used to establish a stable operating point, as shown in fig. 5.80 (a). The current in the resistance R_E makes a voltage drop in the emitter lead that is in the direction of reverse bias for the emitter junction. But, this junction must be forward biased, the base voltage is taken from the supply through the R_1R_2 network.

This circuit makes an improvement in stability. The reason is given as follows –

Suppose I_C tends to rise, because I_{CO} is increased due to an elevated temperature, so the current in R_E rises. Hence, there is a rise in voltage drop across R_E, the base current is reduced. Therefore, I_C will rise less than it would have, if there is no self-biasing resistor R_E.



(a) A Self-biasing Circuit *(b) Thevenin Equivalent Circuit*

Fig. 5.80

Analysis of Self-bias Circuit – For given values of circuit components in the self-bias circuit of fig. 5.80 (a), the quiescent point is found as follows –

Applying KVL in the collector circuit, we get –

$$-V_{CC} + I_C(R_C + R_E) + I_B R_E + V_{CE} = 0 \qquad \text{...(i)}$$

The drop in R_C because of I_B is ignored in comparison to that due to I_C. Hence, this relationship between I_C and V_{CE} is a straight line whose slope given by $R_C + R_E$. This intercept at $I_C = 0$ which is $V_{CE} = V_{CC}$. This load line is drawn on the collector characteristics.

If the circuit of fig. 5.80 (a), is replaced by its Thevenin equivalent, the circuit of fig. 5.80 (b) is obtained, where

$$V = \frac{R_2 V_{CC}}{R_1 + R_2}, R_B = \frac{R_1 R_2}{R_1 + R_2} \qquad \text{...(ii)}$$

Now, applying KVL around the base circuit,

$$V = V_{BE} + I_B R_B + (I_B + I_C) R_E \qquad \text{...(iii)}$$

Now, on substituting the value of I_C from equation (iii) into equation (i), a relationship between I_B and V_{CE} obtained. V_{CE} is calculated for every value of I_B given on the collector curves. A plot on the CE output characteristics which is the locus of these corresponding points V_{CE} and I_B, is known as the ***bias curve***. The intersection of the bias curve and load line provides the quiescent point.

In the cases, where β is known but transistor characteristics are not available, the calculation of Q point is carried out analytically as follows –

The collector current in the active region is given by the expression,

$$I_C = \beta I_B + (1 + \beta) I_{CO} \qquad \text{...(iv)}$$

Now, the values of I_B and I_C are obtained by solving equations (iii) and (iv).

Q.101. Compare the moving coil and moving iron instruments.

(R.G.P.V., May 2019)

Ans. Comparison between moving coil and moving iron instruments are given below –

S.No.	***Moving coil (MC) instruments***	***Moving iron (MI) instruments***
(i)	Moving coil instruments are more accurate.	Moving iron instruments are less accurate than moving coil type.
(ii)	Manufacturing cost is high.	Cheap in cost.
(iii)	Eddy current damping is used.	Air friction damping is used.
(iv)	Controlling torque is provided by spring.	Controlling torque is provided by gravity or spring.
(v)	It works on the principle of D.C. motor.	It works on the principles of magnetism.
(vi)	Lower power consumption.	Slightly high power consumption.
(vii)	These instruments have uniform scale.	They have non-uniform scale.

(viii)	These instruments can be used only for D.C. measurements.	These instruments can be used for A.C. as well as D.C. measurements.
(ix)	Deflection torque is proportional to the current.	Deflection torque is proportional to the square of the current.
(x)	Delicate, sensitive and accurate.	Robust, reliable, and accurate.

Q.102. What are the advantages of electromechanical measuring instruments ? ***(R.G.P.V., May 2019)***

Ans. There are several advantages of traditional electromechanical instruments – Simplicity, reliability, low price. The most important advantage is that the majority of such instruments can work without any additional power supply. Since people's eyes are sensitive to movement also this psycho-physiological aspect of analogue indicating instruments (with moving pointer) is appreciated.

Q.103. Give the pin diagram and its description for IC78XX. ***(R.G.P.V., May 2019)***

Ans. Voltage sources in a circuit may have fluctuations resulting in not providing fixed voltage outputs. A voltage regulator IC maintains the output voltage at a constant value. 7805 IC, a member of 78XX series of fixed linear voltage regulators used to maintain such fluctuations, is a popular voltage regulator integrated circuit (IC). The XX in 78XX indicates the output voltage it provides. 7805 IC provides +5 volts regulated power supply with provisions to add a heat sink. The pin diagram of IC 7805 is shown in fig. 5.81.

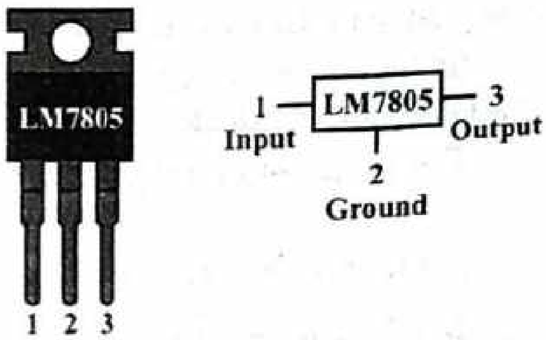


Fig. 5.81 IC 7805 Pin Diagram

Pin Details of 7805 IC –

Pin No.	*Pin*	*Function*	*Description*
1	INPUT	Input voltage (7V-35V)	In this pin of the IC positive unregulated voltage is given in regulation.
2	GROUND	Ground (0V)	In this pin where the ground is given. This pin is neutral for equally the input and output.
3	OUTPUT	Regulated output; 5V (4.8V-5.2V)	The output of the regulated 5V volt is taken out at this pin of the IC regulator.

●●●

RGPV

B.E. (First/Second Semester) EXAMINATION, Dec., 2011
(Common for all Branches)
BASIC ELECTRICALS
AND ELECTRONICS ENGINEERING [BE – 104 (GS)]

Note : Attempt *one* question from each Unit. All questions carry equal marks. Assume suitable data if necessary.

Unit-I

1. (a) What do you understand by dependent and independent sources ? Explain with neat sketches. (See Unit-I, Page 5, Q.5)

(b) State superposition theorem. In the given network, making use of superposition theorem, determine the currents in resistors R_1, R_2 and R_3 and also the currents in voltage source E.

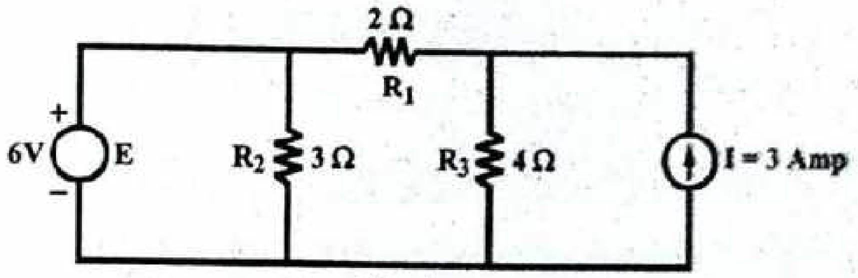


Fig. 1

(See Unit-I, Page 23, Prob.5)

Or

2. (a) Voltage $v(t) = v_0 \cos(\omega t + \phi)$ is applied to a series circuit containing resistor R, inductor L and capacitor C. Obtain expression for the steady state current.

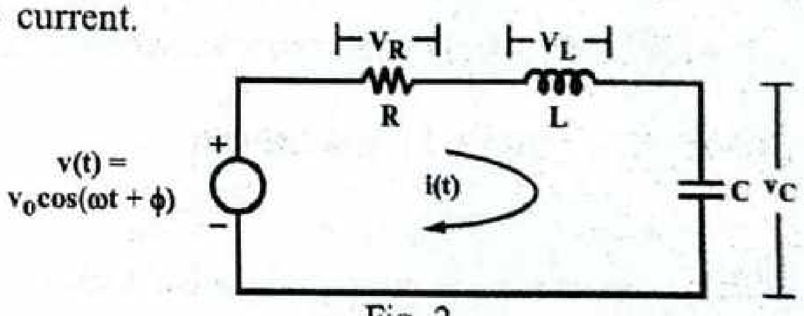


Fig. 2

(b) Describe star connection method for interconnection of 3-phase supply. (See Unit-II, Page 90, Q.52)

Unit-II

3. (a) (i) State Faraday's law of electromagnetism. (See Unit-III, Page 144, Q.30)

(ii) What is meant by turn ratio in transformer ? (See Unit-III, Page 148, Q.41)

(iii) What is magneto-motive force ? (See Unit-III, Page 115, Q.5 (i))

(iv) Mention the *two* important electrical performances of transformer.

(b) Explain the principle of operation of transformer with suitable sketches. **(See Unit-III, Page 147, Q.35)**

Or

4. (a) The O.C. and S.C. tests on a 5 kVA, 230/110 V, 50 Hz transformer gave the following data :

O.C. test (H. V. side) –	230 V,	0.6 A,	80 W
S.C. test (L.V. side) –	6 V,	15 A,	20 W

Calculate percentage efficiency and regulation of a transformer on full load at 0.8 p.f. lagging. **(See Unit-III, Page 172, Prob.12)**

(b) Derive the condition for maximum efficiency of a transformer. **(See Unit-III, Page 166, Q.62)**

Unit-III

5. (a) Derive the expression for generated voltage in D.C. machine. **(See Unit-IV, Page 187, Q.16)**

(b) Draw and explain the construction of a single-phase induction motor with neat sketches. **(See Unit-IV, Page 200, Q.26)**

Or

6. (a) Obtain an expression for e.m.f. equation of 3-phase induction motor. **(See Unit-IV, Page 215, Q.44)**

(b) What are the different methods of speed control in D.C. motor ? Discuss in details. **(See Unit-IV, Page 193, Q.23)**

Unit-IV

7. (a) Convert the following numbers into decimal :

(i) $(11111111)_2$ (ii) $(100)_8$ (iii) $(FFFF)_{16}$

(iv) $(01010101)_2$ (v) $(100.100)_2$

(See Unit-V, Page 237, Prob.3)

(b) Give the logic symbol and truth table for the following logic gates (any *two*) :

(i) NAND (ii) NOR (iii) NOT (iv) EX-OR

(See Unit-V, Page 252, Q.29)

Or

8. (a) Distinguish between combinational and sequential logic circuits giving example of each. **(See Unit-V, Page 257, Q.33)**

(b) Draw the circuit diagram of a half adder and derive its truth table.

(See Unit-V, Page 259, Q.36)

Unit-V

9. (a) (i) Name any *three* materials which are most widely used as semiconductors. **(See Unit-V, Page 268, Q.48)**

(ii) What type of semiconductor results when silicon is doped with (a) donor impurities (b) acceptor impurities ?

(See Unit-V, Page 268, Q.52)

(iii) What is doping ? (See Unit-V, Page 268, Q.51)

(iv) What is intrinsic semiconductor ? (See Unit-V, Page 268, Q.49)

(v) What is operating points ? (See Unit-V, Page 309, Q.97)

(b) Explain the forward and reverse bias operation and voltage-current characteristics of a P-N junction diode. (See Unit-V, Page 278, Q.69)

Or

0.(a) Explain the working of bipolar junction transistor in common emitter configuration. (See Unit-V, Page 296, Q.92)

(b) Explain how a BJT can be used as (i) An amplifier (ii) switch.

(See Unit-V, Page 297, Q.94)

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B.E. (First/Second Semester) EXAMINATION, June, 2012
(Grading System)
(Common for all Branches)
BASIC ELECTRICALS
AND ELECTRONICS ENGINEERING [BE – 104 (GS)]

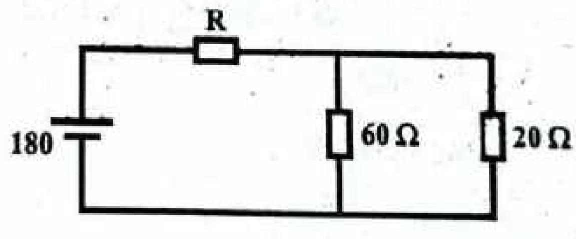
Note : Attempt all the questions. All questions carry equal marks.

1. Answer any two of the following –

(a) State the Norton's theorem. In the circuit shown below determine–

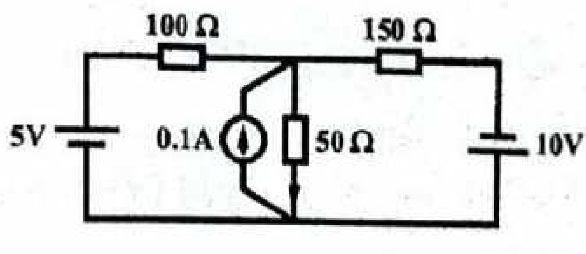
(i) The value of R so that the load of 20 ohm draws maximum power.

(ii) The value of maximum power drawn by the load.

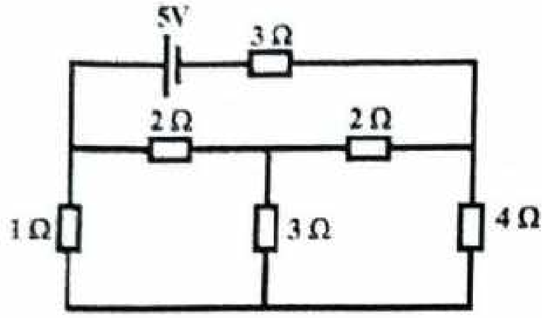


(See Unit-I, Page 28, Prob.10)

(b) State superposition theorem. Apply the same for finding the current in 50 ohm resister with the reference direction shown in circuit.



(c) Determine the current drawn from the 5 volt battery in the network shown.



(See Unit-I, Page 35, Prob.13)

(d) Explain the following terms –

(i) RMS [See Unit-II, Page 45, Q.4 (ii)]

(ii) Average value [See Unit-II, Page 45, Q.4 (i)]

(iii) Active Power [See Unit-II, Page 61, Q.24 (i)]

(iv) Reactive power [See Unit-II, Page 61, Q.24 (ii)]

2. Answer any two of the following –

(a) Explain the following w.r.t. transformer –

(i) Losses (ii) Voltage regulation

(See Unit-III, Page 164, Q.57)

(b) Draw the phasor diagram of a single phase transformer with an inductive load. Write down the procedure in steps for drawing the phasor diagram.

(See Unit-III, Page 155, Q.51)

(c) A 11 KV/400 V distribution transformer takes a no load primary current of 1 amp at a power factor of 0.24 lagging. Find –

(i) The core loss current

(ii) The magnetizing current

(iii) The iron loss

(d) Give reasons why –

(i) Rating of transformer is specified in KVA and not in KW.

(See Unit-III, Page 161, Q.54)

(ii) Core losses are called iron losses (See Unit-III, Page 162, Q.55)

(iii) Cooling is required in transformer (See Unit-III, Page 171, Q.67)

(iv) Cores of transformer is laminated with laminated sheets.

 (See Unit-III, Page 161, Q.53)

3. Answer any two of the following –

(a) Draw torque-slip characteristics of a 3 phase induction motor. Explain the concept of slip. (See Unit-IV, Page 219, Q.51)

(b) Give reasons why –

(i) Starting current is high in dc motor (See Unit-IV, Page 188, Q.17)

(ii) Induced emf in a dc motor is called back emf

(See Unit-IV, Page 188, Q.19)

(c) Specify the application of following motors in field (minimum two)

(i) Three phase induction motor

(ii) Synchronous motor

(iii) DC motors

(iv) Single phase induction motor.

(See Unit-IV, Page 225, Q.55)

(d) A 3 phase, 6 pole induction motor runs at 960 rpm on full load. It is supplied from a 4 pole alternator running at 1500 rpm. Calculate full load slip of the motor. (See Unit-IV, Page 222, Prob.8)

Answer any two of the following –

(a) Obtain the following –

(i) Binary equivalent of $(123\ 72)_8$

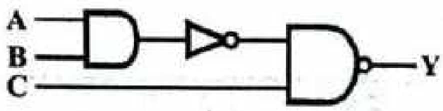
(ii) Octal equivalent of $(10010110.1011)_2$

(iii) Hexadecimal equivalent of $(2391)_{10}$

(iv) Decimal equivalent to $(11011000)_2$.

(See Unit-V, Page 236, Prob.2)

(b) Draw the truth table of the following logic circuit



(See Unit-V, Page 256, Prob.10)

(c) State and prove De-morgan's theorem using two variables.

(See Unit-V, Page 243, Q.20)

(d) Explain the operation of following flip-flops.

(i) J-K flip-flop (See Unit-V, Page 265, Q.45)

(ii) R-S flip-flop. **(See Unit-V, Page 264, Q.43)**

5. Answer any two of the following –

(a) Compare the CE, CB and CC configuration of BJT on the basis of –

(i) Input resistance (ii) Output resistance

(iii) Voltage gain (iv) Current gain.

(See Unit-V, Page 287, Q.83)

(b) Specify the following terms –

(i) Forbidden energy gap **(See Unit-V, Page 269, Q.53)**

(ii) Intrinsic semiconductor **(See Unit-V, Page 268, Q.49)**

(iii) Doping **(See Unit-V, Page 268, Q.51)**

(iv) Charge carriers **(See Unit-V, Page 269, Q.54)**

(v) Biasing. **(See Unit-V, Page 300, Q.98)**

(c) Explain the operation of BJT under following mode –

(i) Cutoff mode (ii) Active mode (iii) Saturation mode.

(See Unit-V, Page 293, Q.89)

(d) Distinguish the following –

(i) Semiconductor and Insulator **(See Unit-V, Page 270, Q.58)**

(ii) P-Type and N-Type materials. **(See Unit-V, Page 270, Q.57)**

RGPV

B.E. (First/Second Semester) EXAMINATION, Dec., 2012

(Grading System)

(Common for all Branches)

BASIC ELECTRICALS

AND ELECTRONICS ENGINEERING

[BE – 104 (GS)]

Note : Attempt all questions.

Unit-I

1. A 400 volt, 3 phase 4 wire system supplies resistive loads between each of the three lines and neutral. Calculate the lines and neutral current when the phase sequence is RYB. 7

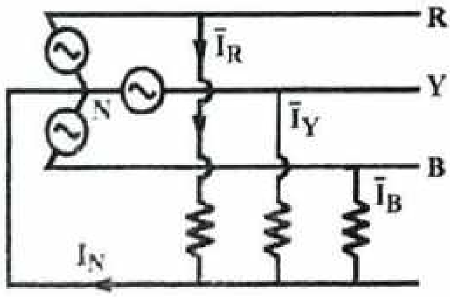


Fig. 1

2. (a) State Thevenin's Theorem giving an example. 4

(See Unit-I, Page 17, Q.20)

(b) Using Thevenin's Theorem find the current flowing through 6Ω resistor of the network shown in fig. 2. 3

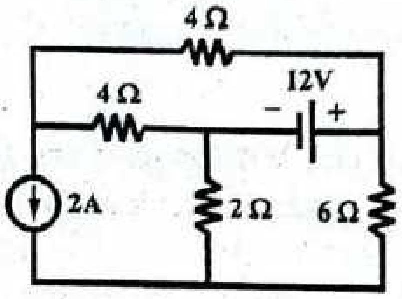


Fig. 2

(See Unit-I, Page 26, Prob.8)

Or

3. A balanced star connected load is supplied from a symmetrical 3 phase 400 volt (line to line) supply. The current in each phase is 50 Amp and lags 30° behind phase voltage. Find – 7

(a) Phase voltage

(b) Phase impedance

(c) Active and reactive power drawn by the load. Also draw the phasor diagram for the same. (See Unit-II, Page 98, Prob.11)

4. Explain in brief the following – 7

(a) Active and reactive power (See Unit-II, Page 61, Q.24)

(b) Apparent power (See Unit-II, Page 61, Q.24)

(c) Power factor (See Unit-II, Page 56, Q.16)

(d) Balanced and unbalanced supply (See Unit-II, Page 90, Q.51)

(e) Superposition theorem. (See Unit-I, Page 15, Q.17)

Unit-II

5. What are the assumptions made for an ideal transformer ? Draw the equivalent circuit and phasor diagram of an ideal transformer. 7

(See Unit-III, Page 150, Q.43)

6. An audio frequency transformer in employed to couple a 60Ω resistive load to a source of 6 volt in series with the resistance of 2400Ω. 7

(a) Determine the transformer turns -ratio to ensure the maximum power is transferred to the load.

(b) Calculate the value of maximum power and corresponding load current and voltage.

(See Unit-III, Page 175, Prob.15)

7. How transformer is used for impedance transformation ? Explain the no load test used for the transformer parameter determination. 7

(See Unit-III, Page 169, Q.65)

8. State Ampere's circuit law. What is mmf and flux density. How ampere circuital law is used in magnetic circuit analysis ? Explain Hysteresis and Eddy current losses. (See Unit-III, Page 164, Q.59) 7

Unit-III

9. Explain the constructional and operational feature of a DC machine with the help of neat diagram. (See Unit-IV, Page 186, Q.14) 7

10. A three phase 440 volt, 50 hp, 50 Hz induction motor delivers rated output power at 1440 rpm. Find 7

(a) No. of poles of machine

(b) Synchronous speed

(c) Slip

(d) Slip rpm

(e) Rotor speed w.r.t.

(i) Rotoro structure (ii) Stator (iii) Stator rotating mmf.

(f) Rotor emf at operating speed if stator to rotor turn ratio is 1 : 0.5. Assume winding factor is unity. 7

(See Unit-IV, Page 222, Prob.9)

Or

11. What is the basic working principle of synchronous machine ? 7

(See Unit-IV, Page 207, Q.34)

12. Explain Torque-slip characteristics of a 3-phase induction motor. 7

(See Unit-IV, Page 218, Q.49)

Unit-IV

13. State De-morgan's theorem. Specify the truth table and logic diagram for full adder circuit. (See Unit-V, Page 259, Q.35) 7

14. Draw the logic diagram for J-K flip flop. Explain its operation. 7

(See Unit-V, Page 265, Q.45)

Or

15. Explain the operation of clocked R-S flip flop with the help of logical diagram, truth table, symbol and characteristic equation. 7

(See Unit-V, Page 264, Q.44)

16. Convert the following numbers into decimal. 7

(i) $(1001010.0101)_2$ (ii) $(12212)_3$ (iii) $(8.3)_9$

Also find the 2's complement of

(i) $(110110)_2$ (ii) $(10000)_2$

(See Unit-V, Page 238, Prob.5)

Unit-V

17. Draw the V-I characteristics of a germanium Diode. Explain the same. 7

(See Unit-V, Page 276, Q.67)

18. Why BJT's are used ? Explain the working of a CB transistor. 7

Or

19. Discuss the three configuration of transistor. How do they differ from each other ? (See Unit-V, Page 286, Q.82) 7

20. What happens to the conductivity of the semiconductor and a metal when temperature is increased. Discuss with reason. 7

(See Unit-V, Page 278, Q.70)

RGPV

B.E. (First/Second Semester) EXAMINATION, June, 2013
BASIC ELECTRICALS AND ELECTRONICS ENGINEERING
(BE – 104)

Note : Attempt all the questions.

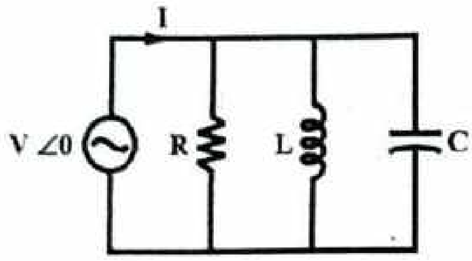
1. (a) Distinguish the following :

(i) 3 phase balanced and unbalanced supply with phasor diagram. 3

(See Unit-II, Page 98, Q.57)

(ii) Voltage source and current source. (See Unit-I, Page 3, Q.2) 4

(b) (i) Obtain current I in the given R-L-C parallel circuit under resonant condition. Justify your answer. 3



(See Unit-I, Page 76, Q.38)

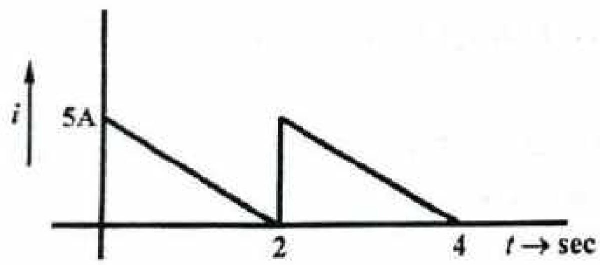
(ii) Obtain resultant voltage when two sources of emfs having $e_1 = 100 \sin \omega t$ and $e_2 = 100 \sin\left(\omega t - \frac{\pi}{6}\right)$ are connected in series.

If resultant voltage is applied to circuit of impedance $(8 + j3)\Omega$, calculate the power (active) supplied to the impedance. 4

(See Unit-II, Page 85, Prob.9)

Or

2. (a) Find the average and RMS value of the following waveforms. Also calculate form factor and peak factor of the same. 7



(See Unit-II, Page 51, Prob.2)

(b) Explain Thevenin's & superposition theorem giving an application example for each. (See Unit-I, Page 18, Q.21) 7

3. (a) Explain basic principle of operation of a transformer. Draw an equivalent circuit of single phase transformer. (See Unit-III, Page 154, Q.46) 7

(b) A single phase transformer rated 570 watt has an efficiency of 95 percent when working at full load and half full load, both at unity PF. Calculate its efficiency at 75 percent of full load. 7

(See Unit-III, Page 175, Prob.16)

Or

4. (a) Specify the following w.r.t. transformer.

(i) All day efficiency 3

(ii) Losses in the transformer 4

(See Unit-III, Page 166, Q.63)

(b) How will you determine the transformer losses in the laboratory ? 7

(See Unit-III, Page 171, Q.66)

5. (a) Draw Torque-slip characteristics of three phase induction motor and explain its stable and unstable region of operation. 7

(See Unit-IV, Page 219, Q.50)

(b) Answer the following w.r.t. induction motor

(i) What is the frequency of rotor currents of an induction motor ? 3

(See Unit-IV, Page 214, Q.43)

(ii) Why is an induction motor called asynchronous ? 2

(See Unit-IV, Page 214, Q.43)

(iii) What do you mean by space phase difference ? 2

Or

6. (a) State the types of dc motors. Discuss constructional details of any type of dc motor. (See Unit-IV, Page 184, Q.11) 7

(b) A shunt generator delivers 50 kw at 250 V and 400 r.p.m. The armature and field resistances are 0.02 Ω and 50 Ω respectively. Calculate the speed of the machine running as shunt motor and taking 50 kw input at 250 V. (See Unit-IV, Page 198, Prob.3) 7

7. Answer the following (any four) : 14

(a) What are logic gates. Enlist the different types of logic gates.

(See Unit-V, Page 245, Q.23)

(b) What is an EX-NOR gate ? Write its truth table.

(See Unit-V, Page 253, Q.31)

(c) Verify that the following operations are commutative and associative.

(i) AND (ii) OR (iii) EX-OR

(See Unit-V, Page 243, Q.19)

(d) Implement the following logic expressions with logic gates :

$y = ABC + AB + BC$

$y = ABC(D + EF)$

(See Unit-V, Page 256, Prob.11)

(e) Design a full adder circuit using NAND gates.

(See Unit-V, Page 259, Q.37)

(f) State and explain De Morgan's theorem. **(See Unit-V, Page 243, Q.20)**

(g) How will you convert decimal number in octal.

(See Unit-V, Page 230, Q.9)

8. Answer the following (any four) – 14

(a) Draw input/output characteristics of a transistor in CE configuration.

(See Unit-V, Page 295, Q.91)

(b) Discuss DC biasing of BJT. **(See Unit-V, Page 300, Q.98)**

(c) How BJT can be used a

(i) Switch

(ii) Inverter.

(See Unit-V, Page 298, Q.96)

(d) Discuss V-I characteristic of P-N Diode. **(See Unit-V, Page 276, Q.67)**

(e) Which transistor configuration CC, CB & CE is suitable for amplifier and why ? **(See Unit-V, Page 287, Q.84)**

(f) Differentiate between intrinsic & extrinsic semiconductor.

(See Unit-V, Page 268, Q.50)

RGPV

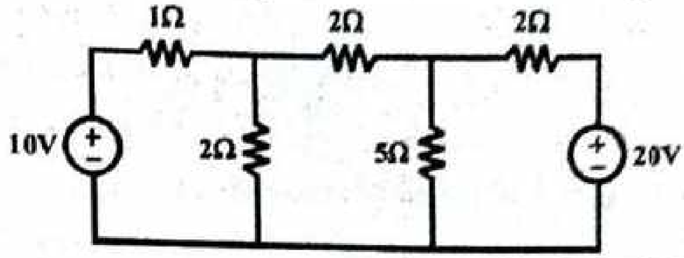
B.E. (First/Second Semester) EXAMINATION, Dec. 2013
BASIC ELECTRICALS AND ELECTRONICS ENGINEERING
(BE – 104)

Note : Attempt all the questions. Every question has internal choice.

1. (a) State and explain superposition theorem. 7

(See Unit-I, Page 15, Q.17)

(b) Calculate current through 5 ohm resistance using loop analysis. 7



(See Unit-I, Page 34, Prob.12)

Or

2. (a) Define the following : 7

(i) Average value of AC voltage [See Unit-II, Page 45, Q.4 (i)]

(ii) RMS valueofAC voltage [See Unit-II, Page 45, Q.4 (ii)]

(iii) Power factor (See Unit-II, Page 56, Q.16)

(iv) Active power [See Unit-II, Page 61, Q.24 (i)]

(v) Reactive power [See Unit-II, Page 61, Q.24 (ii)]

(vi) Apparent power [See Unit-II, Page 61, Q.24 (iii)]

(vii) Three phase balanced supply. [See Unit-II, Page 90, Q.51)

(b) A coil of resistance 10 Ω and inductance 0.1 H is connected in series with 150 μF capacitor across a 200 V, 50 Hz supply calculate : 7

(i) Inductive reactance (ii) Capacitive reactance

(iii) Impedance (iv) Current

(v) Power factor (vi) Voltage across the coil

(vii) Voltage across capacitor.

(See Unit-II, Page 83, Prob.7)

3. (a) Derive EMF equation for single phase transformer. 7

(See Unit-III, Page 149, Q.41)

(b) A single phase transformer is connected across 200 V, 50 Hz supply. Number of turns in primary is 500 while in secondary is 1000. The net cross sectional area of the core is 80 cm^2 calculate : 7

(i) Transformation Ratio

(ii) Maximum flux density in core

(iii) EMF induced in secondary winding.

(See Unit-III, Page 158, Prob.9)

4. (a) What quantities can be find out using open circuit test on 1ϕ transformer ? Explain how you can perform open circuit test on 1ϕ transformer in the laboratory ? (See Unit-III, Page 171, Q.66) 7

(b) A 100 KVA, 1000/10,000 V, 50 Hz single phase transformer has an iron loss of 1100 W. The copper loss with 5A in the high voltage winding is 400 W. Calculate efficiency at 100% normal load for p.f 1.0 and 0.8. **(See Unit-III, Page 177, Prob.18)** 7

5. (a) Describe the constructional details of D.C. machine giving suitable diagram. **(See Unit-IV, Page 181, Q.6)** 7

(b) What do you mean by separately excited and self excited D.C. generator sketch following type of D.C. generator :

(i) Shunt wound

(ii) Series wound

(iii) Compound generator.

(See Unit-IV, Page 184, Q.12)

6. Draw and explain torque-slip characteristic of 3-phase induction. 14

(See Unit-IV, Page 218, Q.49)

7. (a) State and prove De-morgan's theorem. 7

(See Unit-V, Page 243, Q.20)

(b) Write and explain truth table of 7

(i) NAND gate (ii) EX-OR gate. **(See Unit-V, Page 253, Q.30)**

Or

8. (a) Draw and explain with the help of truth table working of J-K flip-flop. **(See Unit-V, Page 265, Q.45)** 7

(b) Draw and explain 4-bit full adder circuit. 7

(See Unit-V, Page 260, Q.38)

9. Explain operation of P-N junction diode when it is 14

(i) Forward bias

(ii) Reverse bias.

(See Unit-V, Page 276, Q.66)

Or

10. (a) Explain the working of transistor when it is operated in CE mode. 7

(See Unit-V, Page 296, Q.92)

(b) Explain in short application of transistor. 7

(See Unit-V, Page 298, Q.96)

RGPV

B.E. (First/Second Semester) EXAMINATION, June 2014
BASIC ELECTRICALS
AND ELECTRONICS ENGINEERING
(BE – 104)

ote : (i) Answer five questions. In each question part A, B, C is compulsory and D Part has internal choice.

(ii) All parts of each questions are to be attempted at one place.

(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3 marks, part D (Max. 400 words) carry 7 marks.

(iv) Except numericals, Derivation, Design and Drawing etc.

1. (a) Define voltage and current sources. **(See Unit-I, Page 3, Q.2)**

(b) Distinguish between Dependent sources and Independent sources. **(See Unit-I, Page 5, Q.5)**

(c) How will you obtain the current through single phase load of 2 kW with PF = 0.8 at 230 Volts. Find active power, reactive power and apparent power for the given load.

(d) Establish the physical meaning of reactive power with the help of necessary derivation.

Or

Distinguish between 3 phase balanced and unbalanced supply. What is the impact of unbalanced load on the power supply ?

(See Unit-II, Page 98, Q.57)

Answer the following with reference to single phase transformer :

(a) Justify with reason the constant flux in the core with variation in load connected to secondary terminal.

(b) Draw phasor diagram of single phase transformer for an inductive load. What variation is observed for a capacitive load ?

(See Unit-III, Page 155, Q.50)

(c) Specify the application of 'equivalent circuit'.

(See Unit-III, Page 154, Q.48)

(d) A 500 KVA transformer has 90% efficiency at full load and at 70% of full load both at upf.

(i) Separate out the transformer losses.

(ii) Determine the transformer efficiency at 80% of full load, upf.

(See Unit-III, Page 176, Prob.17)

Or

A coil wound on an iron core is excited from an ac source at voltage

(b) A 100 KVA, 1000/10,000 V, 50 Hz single phase transformer has an iron loss of 1100 W. The copper loss with 5A in the high voltage winding is 400 W. Calculate efficiency at 100% normal load for p.f 1.0 and 0.8. (See Unit-III, Page 177, Prob.18) 7

5. (a) Describe the constructional details of D.C. machine giving suitable diagram. (See Unit-IV, Page 181, Q.6) 7

(b) What do you mean by separately excited and self excited D.C. generator sketch following type of D.C. generator :

(i) Shunt wound

(ii) Series wound

(iii) Compound generator.

(See Unit-IV, Page 184, Q.12)

6. Draw and explain torque-slip characteristic of 3-phase induction. 14

(See Unit-IV, Page 218, Q.49)

7. (a) State and prove De-morgan's theorem. 7

(See Unit-V, Page 243, Q.20)

(b) Write and explain truth table of 7

(i) NAND gate (ii) EX-OR gate. (See Unit-V, Page 253, Q.30)

Or

8. (a) Draw and explain with the help of truth table working of J-K flip-flop. (See Unit-V, Page 265, Q.45) 7

(b) Draw and explain 4-bit full adder circuit. 7

(See Unit-V, Page 260, Q.38)

9. Explain operation of P-N junction diode when it is 14

(i) Forward bias

(ii) Reverse bias.

(See Unit-V, Page 276, Q.66)

Or

10. (a) Explain the working of transistor when it is operated in CE mode. 7

(See Unit-V, Page 296, Q.92)

(b) Explain in short application of transistor. 7

(See Unit-V, Page 298, Q.96)

RGPV

B.E. (First/Second Semester) EXAMINATION, June 2014
BASIC ELECTRICALS AND ELECTRONICS ENGINEERING
(BE – 104)

Note : (i) Answer five questions. In each question part A, B, C is compulsory and D Part has internal choice.

(ii) All parts of each questions are to be attempted at one place.

(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3 marks, part D (Max. 400 words) carry 7 marks.

(iv) Except numericals, Derivation, Design and Drawing etc.

1. (a) Define voltage and current sources. (See Unit-I, Page 3, Q.2)

(b) Distinguish between Dependent sources and Independent sources.

(See Unit-I, Page 5, Q.5)

(c) How will you obtain the current through single phase load of 2 kW with PF = 0.8 at 230 Volts. Find active power, reactive power and apparent power for the given load.

(d) Establish the physical meaning of reactive power with the help of necessary derivation.

Or

Distinguish between 3 phase balanced and unbalanced supply. What is the impact of unbalanced load on the power supply ?

(See Unit-II, Page 98, Q.57)

2. Answer the following with reference to single phase transformer :

(a) Justify with reason the constant flux in the core with variation in load connected to secondary terminal.

(b) Draw phasor diagram of single phase transformer for an inductive load. What variation is observed for a capacitive load ?

(See Unit-III, Page 155, Q.50)

(c) Specify the application of 'equivalent circuit'.

(See Unit-III, Page 154, Q.48)

(d) A 500 KVA transformer has 90% efficiency at full load and at 70% of full load both at upf.

(i) Separate out the transformer losses.

(ii) Determine the transformer efficiency at 80% of full load, upf.

(See Unit-III, Page 176, Prob.17)

Or

A coil wound on an iron core is excited from an ac source at voltage

V(rms). Derive the expression for maximum flux in the core. Why is it independent of the core reluctance ? (See Unit-III, Page 149, Q.41)

3. (a) Draw the construction of 3 phase induction machine and synchronous machine. (See Unit-IV, Page 212, Q.38)

(b) Develop the emf equation for a 3 phase induction motor. (See Unit-IV, Page 215, Q.44)

(c) Draw the torque slip characteristics of an induction motor. Develop necessary condition for maximum torque. (See Unit-IV, Page 222, Q.53)

(d) Classify DC machines and explain them briefly. (See Unit-IV, Page 184, Q.12)

Or

A series motor runs at 600 rpm when taking a current of 110 A from a 230 volt supply. The useful flux per pole for 110 A is 24 mWb and that for 50 A is 16 mWb. The armature resistance and series field resistance are 0.12 ohms and 0.03 ohms respectively. Calculate the speed when the current has fallen to 50 A.

4. (a) Specify Different number systems used in digital electronics. What are floating numbers ? (See Unit-V, Page 233, Q.13)

(b) State De-Morgan's theorem with example. (See Unit-V, Page 243, Q.20)

(c) Draw the truth table of JK flip-flop along with its logic diagram. (See Unit-V, Page 265, Q.45)

(d) Explain the operation of half adder and full adder along with their logic diagram and truth table. (See Unit-V, Page 257, Q.34)
Also deduce a full adder using EX-OR gate.

Or

Convert the following indicating the steps involved.
(i) $(657)_8 = (?)_{16}$ (ii) $(1053)_{16} = (?)_{10}$ (iii) $(131.F2)_{16} = (?)_{10}$ (See Unit-V, Page 236, Prob.1)

5. (a) Which is the best transistor configuration for amplifiers and why ? (See Unit-V, Page 287, Q.84)

(b) Why Silicon is usually preferred over germanium for fabrication semiconductor devices ? (See Unit-V, Page 271, Q.61)

(c) Explain V-I characteristics and applications of Zener diode. **

(d) Explain the difference between avalanche multiplication and Zener breakdown. **

Or

What are clipper and clamper circuits ? Give one example for each. **

**Now, according to new revised syllabus of R.G.P.V., it is not included in syllabus

How p-n junction is used as rectifier ?

RGPV

B.E. (First/Second Semester) EXAMINATION, Dec. 2014
BASIC ELECTRICALS
AND ELECTRONICS ENGINEERING
(BE – 104)

Note : (i) Answer five questions. In each question part A, B, C is compulsory and D Part has internal choice.
(ii) All parts of each questions are to be attempted at one place.
(iii) All questions carry equal marks, out of which part A and B (Max. 50 words) carry 2 marks, part C (Max. 100 words) carry 3 marks, part D (Max. 400 words) carry 7 marks.
(iv) Except numericals, Derivation, Design and Drawing etc.

Unit-I

. (a) Write the major difference between :
(i) Ideal voltage source and practical voltage source
(ii) Dependent and independent sources.

(See Unit-I, Page 6, Q.6)

(b) Define :
(i) Impedance and (ii) Phase sequence in a.c. circuit.

(See Unit-II, Page 89, Q.48)

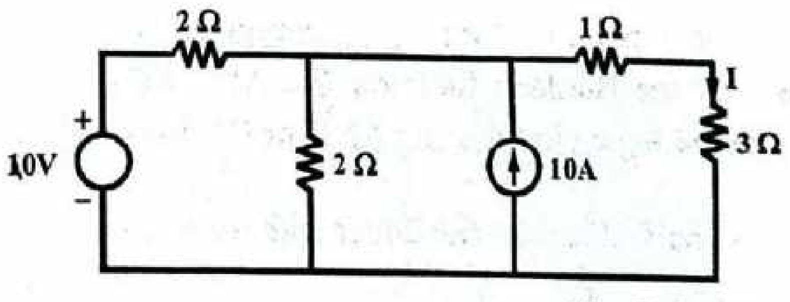
(c) Explain with units and
(i) Real power (See Unit-II, Page 61, Q.24)
(ii) Reactive power (See Unit-II, Page 61, Q.24)
(iii) Apparent power in a.c. circuit. (See Unit-II, Page 61, Q.24)

(d) Drive the relation for conversion for star and delta connection.

(See Unit-I, Page 34, Q.35)

Or

State Thevenin's theorem. Determine the current through a 3Ω resistor branch in the circuit using Thevenin's theorem.



(See Unit-I, Page 27, Prob.9)

Unit-II

2. (a) Define magnetic leakage and fringing. (See Unit-III, Page 115, Q.3)

(b) Give the reason of eddy current loss in transformer core.

(See Unit-III, Page 164, Q.58)

(c) Define voltage regulation and efficiency of a transformer. Give the formula also. **(See Unit-III, Page 165, Q.61)**

(d) Draw the complete phasor diagram of a single phase transformer for an inductive load write the notations used for all voltages and currents used in the phasor diagram. **(See Unit-III, Page 155, Q.51)**

Or

The results of tests performed on 1-ϕ, 20 KVA, 2200/220 volt, 50 Hz. Transformer are as follows –

O.C. test : 220 V, 4.2 A, 148 W

S.C. test : 86 V, 10.5 A, 360 W.

Determine :

The regulation and efficiency at 0.8 p.f. lagging at full load.

(See Unit-III, Page 174, Prob.14)

Unit-III

3. **(a)** Write the necessity and material used for the following in a d.c. machine
   (i) Commutator
   (ii) Brush.

(See Unit-IV, Page 180, Q.5)

(b) Why synchronous machine is called as synchronous ? Define synchronous speed. **(See Unit-IV, Page 203, Q.30)**

(c) Classify self excited D.C. motor. **(See Unit-IV, Page 184, Q.10)**

(d) Derive the e.m.f. equation of a 3 phase Induction Motor.

(See Unit-IV, Page 215, Q.44)

Or

Draw and explain the complete Torque-slip characteristics of 3 phase induction motor. **(See Unit-IV, Page 218, Q.49)**

Unit-IV

4. **(a)** State and explain De Morgan's theorem. **(See Unit-V, Page 243, Q.20)**

(b) Simplify the Boolean function $Z = AB + \overline{A}C + BC$ and therefore design the logic circuit using AND or OR logic gates.

(See Unit-V, Page 254, Prob.8)

(c) Explain half adder and full adder with truth table.

(See Unit-V, Page 257, Q.34)

(d) Explain number systems used in digital electronics.

(See Unit-V, Page 227, Q.4)

Or

Explain in detail J-K flip flop. **(See Unit-V, Page 265, Q.45)**

Unit-V

5. (a) Define ideal diode and practical diode. (See Unit-V, Page 271, Q.60)
   (b) Differentiate between conductor, semiconductor and insulator with example. (See Unit-V, Page 270, Q.59)
   (c) Draw and explain the V-I, characteristic of diode. (See Unit-V, Page 276, Q.67)
   (d) Draw the connection diagram and explain the use and working of CE transistor configuration. (See Unit-V, Page 296, Q.92)

Or

Explain the working of BJT. Discuss DC biasing of BJT. (See Unit-V, Page 300, Q.99)

RGPV

(EE – 111)
B.E. (All Branches), I Year I Semester
EXAMINATION, Dec. 2015
Choice Based Credit System (CBCS)
FUNDAMENTALS OF ELECTRICAL ENGINEERING

Note : Attempt any five questions. All questions carry equal marks.

Unit-I

1. (a) State Thevenin's theorem and explain procedure to apply Thevenin's theorem. Using this theorem find the current in resistance R_L shown in figure.

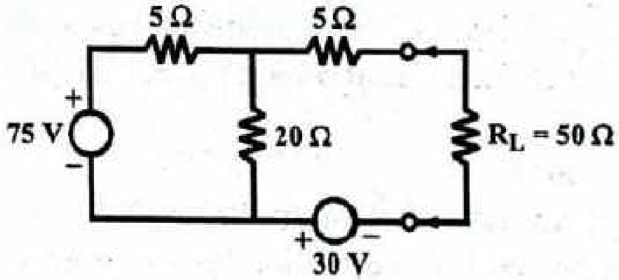


Fig. (See Unit-I, Page 25, Prob.7)

   (b) In the circuit of figure find the voltage V_1 across the 6Ω resistance using nodal method of circuit analysis.

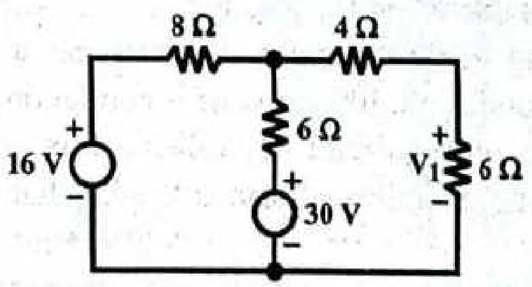


Fig. (See Unit-I, Page 39, Prob.16)

   (c) Reduce the network of figure to obtain the equivalent resistance as seen between nodes ad.

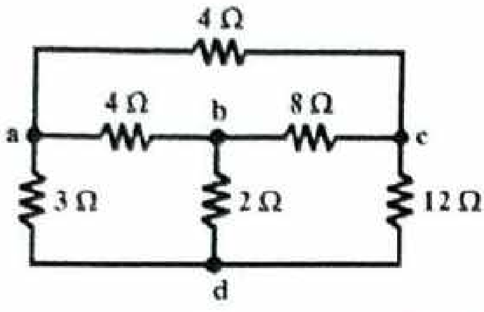


Fig. (See Unit-I, Page 13, Prob.2)

2. (a) Explain what is impedance ? What role does it play in phasor diagrams ? (See Unit-II, Page 60, Q.22)

   (b) Explain the meaning and significance of the power factor of a circuit. (See Unit-II, Page 56, Q.17)

   (c) Two impedances of $Z_1 = 8 + j6$ and $Z_2 = 3 - j4$ are in parallel. If the total current of the combination is 25A. Find the current taken and power taken by each impedance. (See Unit-II, Page 87, Prob.10)

3. (a) Derive the relationship between a line current and a phase current related to a star connected and delta connected load. (See Unit-II, Page 90, Q.52)

   (b) What do you mean by phase sequence in 3-ϕ AC voltage waveform, if 3-ϕ AC voltage waveform is available to a 3-ϕ motor, then how can we revert the phase sequence, and there by direction of rotation of motor. (See Unit-II, Page 89, Q.47)

   (c) A symmetrical 3-ϕ, 400 V system supplies a balanced load of 0.8 lagging power factor and connected in star. If the line current is 34.64 A, find –
   (i) Impedance
   (ii) Resistance and reactance per phase
   (iii) Total power. (See Unit-II, Page 99, Prob.12)

4. (a) Explain how current carrying conductor when placed in a magnetic field experiences a force ? (See Unit-III, Page 139, Q.27)

   (b) Explain with circuit diagrams, the open circuit test and short circuit test to be conducted on 1-ϕ transformer. (See Unit-III, Page 169, Q.65)

   (c) An iron ring of 20 cm mean diameter has a cross section of 100 cm^2, is wound with 400 turns of a conducting wire. Calculate the exciting current required to establish a flux density of 1 Wb/m^2. If the relative permeability of iron is 1000. What is the value of energy stored ? (See Unit-III, Page 126, Prob.1)

5. (a) Explain the procedure to analyse series magnetic circuit with air gap. (See Unit-III, Page 119, Q.8)

   (b) State and explain the law of electromagnetic induction. (See Unit-III, Page 144, Q.30)

(c) A single phase 50 Hz, 250 V (Primary) transformer has 80 turns on primary and 280 turns on secondary side. The area of core is 200 cm^2. Calculate
   (i) Maximum flux density on core
   (ii) Induced emf of secondary side. (See Unit-III, Page 157, Prob.8)

6. (a) Explain the construction and principle of operation of a synchronous motor. (See Unit-IV, Page 208, Q.35)
   (b) Explain how the rotation of an induction motor is produced. (See Unit-IV, Page 214, Q.41)
   (c) Enumerate the various types of losses occurring in electrical machines. (See Unit-IV, Page 224, Q.54)

7. (a) Name the main parts of a D.C. machine and indicate their functions. (See Unit-IV, Page 182, Q.7)
   (b) Derive an expression for induced emf in a transformer in terms of frequency, the maximum value of flux and the number of turns on the windings. (See Unit-III, Page 149, Q.41)
   (c) Discuss the magnetization characteristics of ferromagnetic materials. (See Unit-III, Page 125, Q.12)

RGPV

(EE–111)
B.E. (All Branches), I Year, II Semester,
EXAMINATION, June 2016
Choice Based Credit System (CBCS)
FUNDAMENTALS OF ELECTRICAL ENGINEERING

Note : (i) Attempt any five questions.
(ii) All questions carry equal marks.

1. (a) State and explain Kirchhoff's Law with suitable example. (See Unit-I, Page 32, Q.31)
   (b) Find the value of current 'I'.

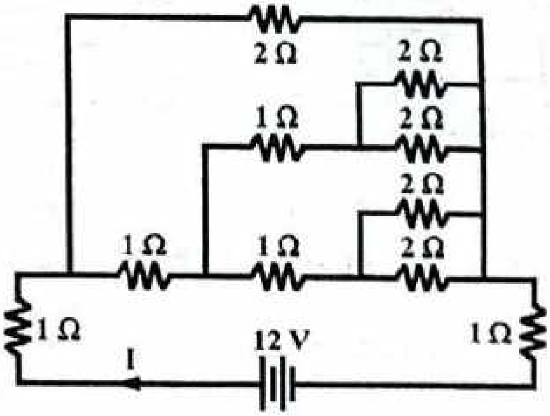


Fig. (See Unit-I, Page 12, Prob.1)

2. (a) Define the following terms –

   (i) Active power (ii) Reactive power

   (iii) Apparent power (iv) Power factor

   (v) Alternation (vi) Frequency

   (See Unit-II, Page 61, Q.25)

   (b) Show that the power consumed by a pure inductive circuit is zero.

   (See Unit-II, Page 64, Q.28)

   (c) Derive an expression for series resonance of a R-L-C series AC circuit. (See Unit-II, Page 77, Q.40)

3. (a) Derive the relation between line quantities and phase quantities for balanced star connections. (See Unit-II, Page 94, Q.53)

   (b) Write down the advantages of 3-ϕ system over single phase system.

   (See Unit-II, Page 89, Q.46)

4. (a) Compare the electrical circuit with magnetic circuit.

   (See Unit-III, Page 116, Q.6)

   (b) Define the following terms –

   (i) MMF (ii) Flux

   (iii) Permeability (iv) Magnetic field intensity

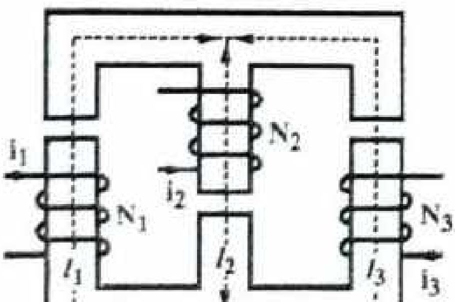
   (v) Susceptance (vi) Magnetic field density.

   (See Unit-III, Page 115, Q.5)

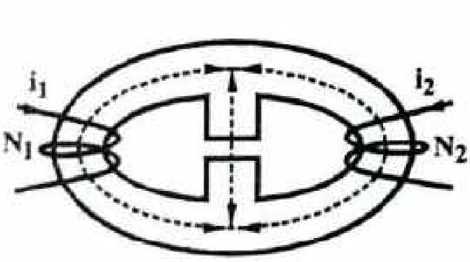
5. (a) State and explain laws of electromagnetic induction.

   (See Unit-III, Page 144, Q.30)

   (b) Draw the electrical equivalent circuit and write down the equivalent equations.



(i)



(ii)

Fig.

6. (a) Derive an EMF equation of a single phase transformer.

   (See Unit-III, Page 149, Q.41)

   (b) Show that the transformer is a constant flux device.

   (See Unit-II, Page 148, Q.40)

   (c) State and explain no load current with their components.

   (See Unit-III, Page 167, Q.64)

7. (a) Write down the constructional features of a D.C. machine with neat and suitable diagrams. (See Unit-IV, Page 181, Q.6)

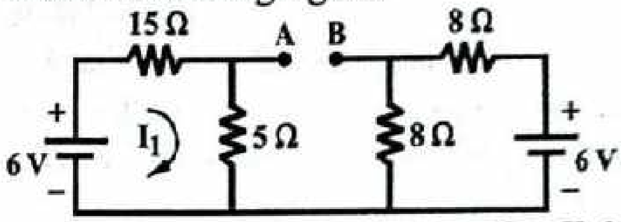
(b) Discuss various types of losses occurs in various electrical machines. (See Unit-IV, Page 224, Q.54)

RGPV

(EE-111)
B.E. (All Branches), I Semester
EXAMINATION, Dec. 2016
Choice Based Credit System (CBCS)
FUNDAMENTALS OF ELECTRICAL ENGINEERING

Note : (i) Total number of questions eight. Attempt any five questions.
(ii) All questions carry equal marks.

1. (a) Find Thevenin's equivalent circuit between terminals A and B for the circuit shown in following figure.

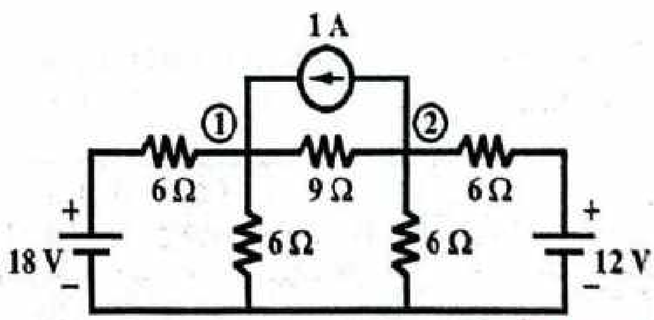


(See Unit-I, Page 24, Prob.6)

(b) A coil of resistance 10 Ω and inductance 0.1 H is connected in series with 150 μF capacitor across a 200 V, 50 Hz supply. Calculate –
(i) Inductive reactance
(ii) Capacitive reactance
(iii) Impedance
(iv) Current
(v) Power factor
(vi) Voltage across capacitor.

(See Unit-II, Page 83, Prob.7)

2. (a) Find current I using nodal analysis.



(See Unit-I, Page 38, Prob.15)

(b) Explain delta/star and star/delta transformations.

(See Unit-I, Page 34, Q.35)

3. (a) Explain measurement of power and power factor in three phase

system with balanced load by using two wattmeter method.

(See Unit-II, Page 106, Q.61)

(b) Establish the relationship between phase and line voltages in a three-phase star connected circuit. (See Unit-II, Page 94, Q.53)

4. (a) Explain the construction and classification of single phase transformer.

(See Unit-III, Page 146, Q.34)

(b) Describe in detail the losses in transformer.

(See Unit-III, Page 162, Q.55)

5. (a) The O.C. and S.C. test conducted on 230/460 V transformer gave following data –

O.C. test (LV side) = 230 V; 1.2 A;85 W

S.C. test (HV side) = 30 V; 14 A; 105 W

Determine the circuit constant. (See Unit-III, Page 172, Prob.13)

(b) Derive E.M.F. equation for a single phase transformer.

(See Unit-III, Page 149, Q.41)

6. (a) A single phase transformer has 350 primary and 1050 secondary turns. The net cross-sectional area of the core is 55 cm^2. If the primary winding be connected to a 400 V, 50 Hz single phase supply, calculate–

(i) Maximum value of flux density in the core

(ii) Voltage induced in the secondary winding.

(See Unit-III, Page 157, Prob.7)

(b) Compare magnetic circuit with electrical circuit in detail.

(See Unit-III, Page 116, Q.6)

7. (a) Describe D.C. machine with neat sketch in viewing of main parts and constructional details.

(See Unit-IV, Page 181, Q.6)

(b) Develop an e.m.f. equation for D.C. generator.

(See Unit-IV, Page 187, Q.16)

8. (a) Explain construction and working principle of three phase induction motor. (See Unit-IV, Page 214, Q.40)

(b) Explain lab method to perform open circuit and short circuit test on single phase transformer. (See Unit-III, Page 169, Q.65)

RGPV

(EE – 111)

B.E. I & II Semester, EXAMINATION, June 2017

Choice Based Credit System (CBCS)

FUNDAMENTALS OF ELECTRICAL ENGINEERING

Note : (i) Total number of questions eight.

(ii) Attempt any five questions.

(iii) All questions carry equal marks.

1. (a) State and explain Thevenin's theorem applicable to electrical circuits.
(See Unit-I, Page 17, Q.20)

(b) Define and explain –

(i) Active, reactive and apparent power
(See Unit-II, Page 61, Q.24)

(ii) Power factor (See Unit-II, Page 56, Q.16)

2. (a) Explain briefly the following as applied to A.C. series and parallel circuits –

(i) Resonance frequency

(ii) Q-factor. (See Unit-II, Page 80, Q.43)

(b) A coil takes 2.5 amps. when connected across 200 volts 50 Hz mains. The power consumed by the coil is found to be 400 watts. Find the inductance and the power factor of the coil.
(See Unit-II, Page 83, Prob.6)

3. (a) State and explain KCL and KVL. (See Unit-I, Page 10, Q.16)

(b) Using superposition theorem, determine the current in 5 ohm resistance.

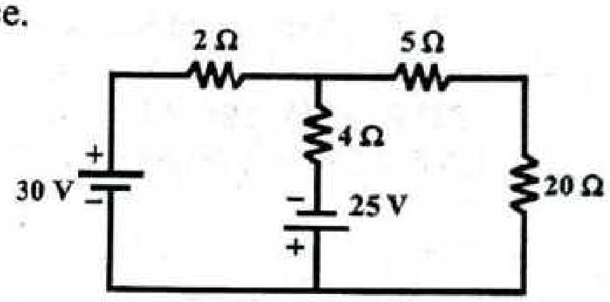


Fig. (See Unit-I, Page 22, Prob.4)

4. (a) Establish relationship between line and phase voltages and current in balanced star connected load. Draw complete phasor diagram of voltages and currents. (See Unit-II, Page 95, Q.53)

(b) A three phase, 440 V motor load has a power factor of 0.6. Two wattmeters connected to measure the power show the input to be 25 kW. Find the reading on each instrument.
(See Unit-II, Page 112, Prob.18)

5. (a) Describe the principle of operation of single phase transformer. What is ideal transformer and transformation ratio ?
(See Unit-III, Page 151, Q.44)

(b) Explain the similarities and dissimilarities between electric and magnetic circuit. (See Unit-III, Page 116, Q.6)

6. (a) A single phase transformer is connected to a 230V, 50 Hz supply. The net cross sectional area of the core is 60 cm^2. The number of turns in the primary is 500 and in the secondary 100. Determine –

(i) Transformation ratio

(ii) Maximum value of flux density in the core

(iii) E.M.F. induced in secondary winding.

(See Unit-III, Page 159, Prob.10)

(b) Specify the necessary condition for a given three-phase balanced system. How will you measure the power in balanced three-phase circuit ? (See Unit-II, Page 106, Q.60)

7. (a) Explain working principle of D.C. motor with necessary diagram.

(See Unit-IV, Page 185, Q.13)

(b) A six pole lap wound D.C. generator has 720 conductors, a flux of 40 mWb per pole is driven at 400 rpm. Find the generated e.m.f.

(See Unit-IV, Page 197, Prob.1)

8. (a) Compare induction machine and synchronous machine on the basis of construction and applications. (See Unit-IV, Page 216, Q.47)

(b) Discuss the effect of hysteresis and eddy current in magnetic circuit.

(See Unit-III, Page 165, Q.60)

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B.E. (First/Second Semester) EXAMINATION, Dec. 2017 BASIC ELECTRICALS AND ELECTRONICS ENGINEERING [(BE–104)]

Note : (i) Attempt any five questions.
(ii) All questions carry equal marks.
(iii) In case of any doubt or dispute the English version question should be treated as final.

1. (a) State and explain with neat diagram Kirchhoff's laws for electrical circuits. (See Unit-I, Page 10, Q.16)

(b) Determine the current's in all branches of the network shown in figure.

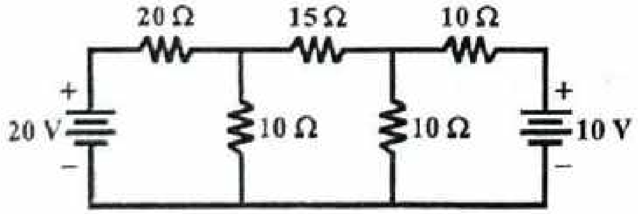

Fig. 1.1 (See Unit-I, Page 36, Prob.14)

2. (a) Discuss various characteristic of a series RLC circuit. Derive mathematical expression in support of your discussion.

(See Unit-II, Page 73, Q.35)

(b) Explain the following terms pertaining to an A.C. wave –
(i) Time period
(ii) RMS value

(iii) Average value (iv) Form factor.

(See Unit-II, Page 47, Q.7)

3. (a) How you will measure power in a three phase A.C. circuit when balanced load is connected across it. (See Unit-II, Page 104, Q.59)

(b) A balanced star connected load of 8 + j6 ohm is connected across three phase, 50 Hz, 440 V supply system. Calculate –
(i) Line current
(ii) Power absorbed
(iii) Reactive volt ampere.

(See Unit-II, Page 99, Prob.13)

4. (a) What is hysteresis loop ? Explain it by drawing hysteresis loop.
(See Unit-III, Page 119, Q.9)

(b) Do the comparison of electrical and magnetic circuit on the basis of similarities and dissimilarities. (See Unit-III, Page 116, Q.6)

5. (a) Write basic principle of operation of transformer and derive its EMF equation. (See Unit-III, Page 150, Q.42)

(b) Derive an approximate equivalent circuit of transformer and discuss the losses in transformer. (See Unit-III, Page 164, Q.56)

6. (a) Develop an EMF equation for D.C. generator.
(See Unit-IV, Page 187, Q.16)

(b) Describe D.C. machine with suitable sketches in viewing of main parts and construction details. (See Unit-IV, Page 181, Q.6)

7. (a) Compare induction machine and synchronous machine on the basis of construction and application. (See Unit-IV, Page 216, Q.47)

(b) The core loss in a 3-phase induction motor is 100 W and equals the mechanical loss, stator copper loss is 150 W. When developing 2000 W as the shaft power. What is the efficiency of the machine. Assume the slip as 4%. (See Unit-IV, Page 223, Prob.10)

8. (a) What is a P-N junction diode ? Sketch the V-I characteristics.
(See Unit-V, Page 278, Q.68)

(b) Explain the following –
(i) P-type and n-type semiconductor
(ii) Half wave and full wave rectifier. (See Unit-V, Page 279, Q.71)

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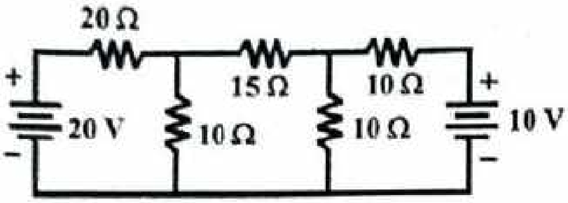
BT-1004 (CBGS)
B.Tech., I & II Semester
EXAMINATION, May 2018
Choice Based Grading System (CBGS)
BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

Note : (i) Attempt any five questions.
(ii) All questions carry equal marks.
(iii) In case of any doubt or dispute the English version question should be treated as final.

1. (a) Explain Kirchhoff's current law and voltage law. 7
(See Unit-I, Page 10, Q.16)

(b) Determine the current's in all branches of the network shown in figure. 7



(See Unit-I, Page 36, Prob.14)

2. (a) What is difference between d.c. and a.c. ? Draw a.c. sine wave and define instantaneous value, average value and R.M.S. value of this a.c. sine wave. **(See Unit-II, Page 45, Q.5)** 7

(b) A 220 volt, 50 Herts supply is given to a series R LC circuit having a resistance of 50 ohm, inductance of 0.2 Henry and capacitance of 100 microfarad. Calculate impedance, current in the circuit and voltage across R, L, C. **(See Unit-II, Page 84, Prob.8)** 7

3. (a) Distinguish between electrical and magnetic circuits. 7

(See Unit-III, Page 116, Q.6)

(b) Explain Faraday's law of electromagnetic induction. 7

(See Unit-III, Page 144, Q.30)

4. (a) Explain principle of working of a Transformer. Explain core and shell type transformer with diagram. **(See Unit-III, Page 147, Q.36)** 7

(b) A 10 kVA transformer has 200 turns on the primary and 40 turns on the secondary winding. The primary is connected to 1000 volts, 50 Hz supply. Calculate the full load secondary current, secondary voltage and maximum flux in the core. 7

(See Unit-III, Page 159, Prob.11)

5. (a) State basic principle of a D.C. motor. Draw diagram of a D.C. machine and name its parts ? **(See Unit-IV, Page 186, Q.14)**

(b) Write the principle of operation of synchronous motor.

(See Unit-IV, Page 207, Q.34)

6. (a) Explain working principle of a 3-ϕ induction motor.

(See Unit-IV, Page 212, Q.39)

(b) Calculate the generated emf of a 8-pole wave wound D.C. generator which is having 720 conductors, flux per pole is 40 mWb and driven at 400 rpm. **(See Unit-IV, Page 197, Prob.2)** 7

7. (a) Converted as directed – 7

(i) $(39)_{10}$ decimal to $(?)_2$ binary

(ii) $(1213)_8$ octal to $(?)_{10}$ decimal

(iiii) $(16E)_{16}$ Hexadecimal to $(?)_2$ binary

(iv) $(10101011)_2$ binary to $(?)_8$ octal.

(See Unit-V, Page 237, Prob.4)

(b) What is a transistor ? Draw electrical symbol of transistor. Also describe the currents in a typical transistor.

(See Unit-V, Page 289, Q.86)

8. Write short notes (any two) –

(a) Star-delta transformations (See Unit-I, Page 34, Q.35)

(b) Thevenin's theorem (See Unit-I, Page 17, Q.20)

(c) Logic gates (See Unit-V, Page 245, Q.23)

(d) J-K Flip Flop. (See Unit-V, Page 265, Q.45)

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BT-104 (CBGS)
B.Tech., I Semester
EXAMINATION, November 2018
Choice Based Grading System (CBGS)
BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

Note : (i) Attempt any five questions.

(ii) All questions carry equal marks.

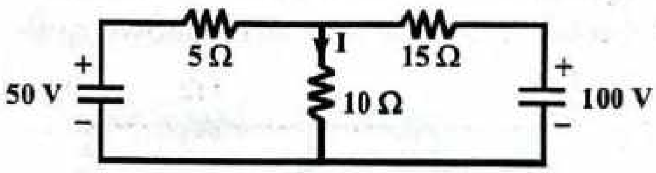
(iii) In case of any doubt or dispute the English version question should be treated as final.

1. For the circuit shown in figure-1 determine the current I through the 10Ω resistance by –

(i) KCL

(ii) KVL

(iii) Superposition theorem.



(See Unit-I, Page 40, Prob.17)

2. (a) What do you understand by average value, RMS value, form factor and peak factor in AC circuit ? (See Unit-II, Page 47, Q.8)

(b) What is active, reactive and apparent power in RLC series circuit ? (See Unit-II, Page 61, Q.24)

3. (a) Explain the meaning of phase sequence and balanced and unbalanced supply and loads. (See Unit-II, Page 98, Q.56)

(b) Determine the power in balanced and unbalanced three phase system and their measurements. (See Unit-II, Page 106, Q.63)

4. (a) Discuss about the magnetization characteristics of ferromagnetic materials. (See Unit-III, Page 125, Q.12)

(b) Discuss the laws of Electromagnetic induction.

(See Unit-III, Page 144, Q.30)

5. Disucss the construction, working principle, emf equation and equivalent circuit of single phase transformer.

(See Unit-III, Page 154, Q.47)

6. (a) Discuss the working principle of 3-phase induction motor.
(See Unit-IV, Page 213, Q.39)
   (b) Differentiate between induction machine and synchronous machine.
(See Unit-IV, Page 216, Q.47)
7. (a) Explain the working of J-K flip flop. (See Unit-V, Page 265, Q.45)
   (b) Discuss the working principle of BJT. (See Unit-V, Page 284, Q.76)
8. Write Short notes on any two of the following –
   (a) OC and SC test in transformer (See Unit-III, Page 169, Q.65)
   (b) Losses in electrical machines (See Unit-IV, Page 224, Q.54)
   (c) RS Flip flop. (See Unit-V, Page 264, Q.43)

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BT-1004 (CBGS)
B.Tech., I & II Semester
EXAMINATION, November 2018
Choice Based Grading System (CBGS)
BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

Note : (i) Attempt any five questions out of eight.
(ii) All questions carry equal marks.
(iii) In case of any doubt or dispute the English version question should be treated as final.

1. (a) State and explain Thevenin theorem. (See Unit-I, Page 17, Q.20)
   (b) Explain the source Transformation technique.
(See Unit-I, Page 8, Q.11)
2. (a) What is the value of unknown resistor R if the voltage drop across the 4Ω resistor is 2V for the circuit shown in figure 1.

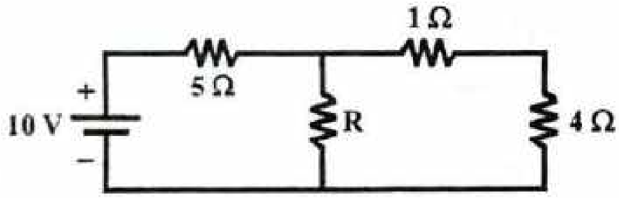

Figure 1 (See Unit-I, Page 14, Prob.3)

   (b) Explain the nodal analysis with suitable example.
(See Unit-I, Page 31, Q.30)
3. (a) Define the following –
   (i) R.M.S. value
   (ii) Form factor
   (iii) Peak factor
   (iv) Time period
   (v) Frequency.
(See Unit-II, Page 47, Q.9)
   (b) Calculate the average and effective values of the waveform shown in figure 2. Hence find the form factor.

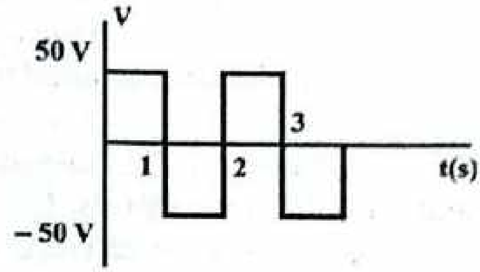

Figure 2 (See Unit-II, Page 51, Prob.3)

4. (a) Explain the advantages of three phase system.
(See Unit-II, Page 89, Q.46)
(b) Explain how power is measured using two wattmeter.
(See Unit-II, Page 106, Q.62)

5. Explain the OC and SC test of a transformer.
(See Unit-III, Page 169, Q.65)

6. (a) Compare magnetic and electric circuits.
(See Unit-III, Page 116, Q.6)
(b) Explain the construction detail of Transformer.
(See Unit-III, Page 145, Q.33)

7. Explain construction, classification and working principle of DC machine.
(See Unit-IV, Page 187, Q.15)

8. Explain the following (any two) –
(a) Bipolar Junction Transistor (BJT) and their working
(See Unit-V, Page 284, Q.76)
(b) R-S flip flop (See Unit-V, Page 264, Q.43)
(c) J-K flip flop (See Unit-V, Page 266, Q.45)
(d) Half adder and full adder. (See Unit-V, Page 257, Q.34)

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BT-104 (CBGS)
B.Tech., I & II Semester
EXAMINATION, May 2019
Choice Based Grading System (CBGS)
BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

Note : (i) Attempt any five questions.
(ii) All questions carry equal marks.
(iii) Assume suitable data, if required.
(iii) In case of any doubt or dispute the English version question should be treated as final.

1. (a) State and prove superposition theorem.
(See Unit-I, Page 15, Q.7)
(b) Compare the moving coil and moving iron instruments.
(See Unit-V, Page 303, Q.101)

2. (a) With a neat diagram explain the working and principle of DC motor.
(See Unit-IV, Page 185, Q.13)

(b) What are the advantages of electromechanical measuring instruments ?
(See Unit-V, Page 304, Q.102)

3. (a) A 30 kW, 30 V DC shunt generator has armature and field resistance of 0.05 ohm and 100 ohm respectively. Calculate the total power developed by the armature when it delivers full output power.
(See Unit-IV, Page 198, Prob.4)

(b) With the help of neat sketches explain the construction and working principle of split phase induction motor.
(See Unit-IV, Page 203, Q.28)

4. (a) Draw and explain the R-L-C series and parallel circuit.
(See Unit-II, Page 77, Q.39)

(b) Write an introductory note on active, reactive and apparent power.
(See Unit-II, Page 61, Q.24)

5. (a) Discuss some of the magnetization characteristics of ferromagnetic materials. (See Unit-III, Page 125, Q.12)

(b) Derive relation that gives the value of force on a current carrying conductor. (See Unit-III, Page 140, Q.27)

6. (a) Explain how a transistor acts as switch ?
(See Unit-V, Page 298, Q.95)

(b) Explain the working of a full wave rectifier.
(See Unit-V, Page 282, Q.72)

7. (a) Differentiate between level and edge triggering. Draw the logic circuit and truth table for J-K flip flop. (See Unit-V, Page 267, Q.46)

(b) Give the pin diagram and its description for IC 78 XX .
(See Unit-V, Page 304, Q.103)

8. Write short notes (any four) –

(a) BJT (See Unit-V, Page 282, Q.73)

(b) De Morgan's Theorem (See Unit-V, Page 243, Q.20)

(c) Kirchhoff's Law (See Unit-I, Page 10, Q.16)

(d) Admittance (See Unit-II, Page 60, Q.23)

(e) 2's complement (See Unit-V, Page 235, Q.16)

(f) Star delta transformation. (See Unit-I, Page 34, Q.35)